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Land Application of Wastewater in Australia. The Werribee Farm System Melbourne, Victoria

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TECHNICAL REPORT

LAND APPLICATION OF WASTEWATER IN AUSTRALIA

THE WERRIBEE FARM SYSTEM, MELBOURNE, VICTORIA

MAY 1975

U.S. Environmental Protection Agency
Municipal Construction Division
Office of Water Program Operations
Washington, D.C. 20460

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TECHNICAL REPORT

LAND APPLICATION OF WASTEWATER IN AUSTRALIA

THE LAND TREATMENT SYSTEM AT WERRIBEE, VICTORIA

operated by

THE MELBOURNE AND METROPOLITAN BOARD OF WORKS

MELBOURNE, VICTORIA

by

BELFORD L. SEABROOK
PROFESSIONAL ENGINEER

MAY 1975

MUNICIPAL CONSTRUCTION DIVISION
OFFICE OF WATER PROGRAM OPERATIONS
U. S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MCD-16

ABBREVIATIONS

Board	-	MMBW-Melbourne and Metropolitan Board of Works
BOD	-	biochemical oxygen demand
cm	-	centimeter
COD	-	chemical oxygen demand
Farm	-	Werribee Farm soil treatment system of MMBW
in.	-	inch
MMBW	-	Melbourne and Metropolitan Board of Works
N	-	nitrogen
mgd	-	million gallons per day
mg/l	-	milligrams per litter
ppm	-	parts per million
P	-	phosphorus
SS	-	suspended solids

TERMS

Conventional secondary treatment - Reduction of pollutant concentrations in wastewater by physical, chemical or biological menas.

Crop irrigation - Application on land of water to meet the growth needs of plants.

Evapotranspiration - The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, snow, or intercepted precipitation in any specified time.

Grass filtration - Same as overland flow.

Land application or Land Treatment - The discharge of wastewater onto the soil for treatment, reuse or crop irrigation.

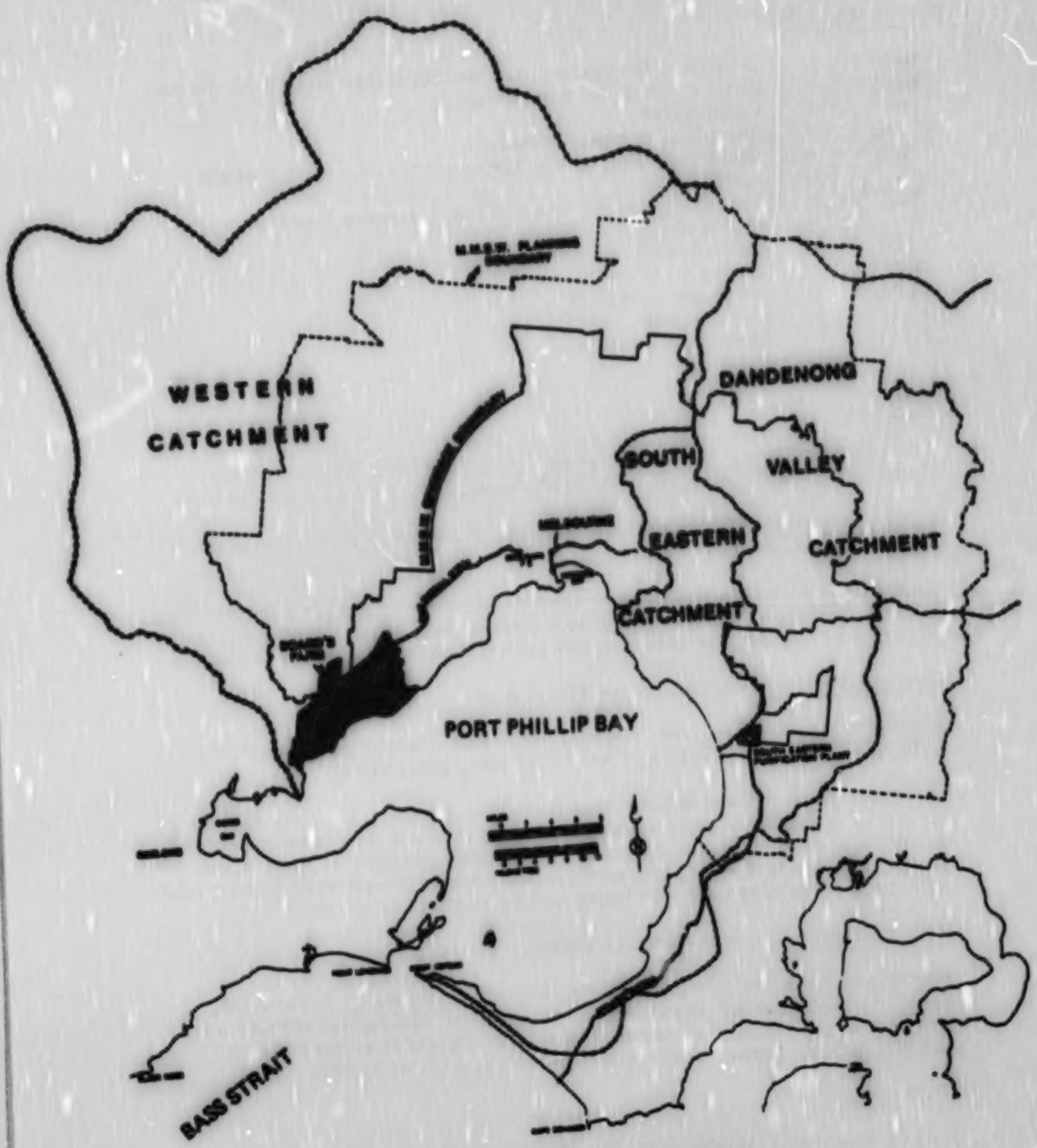
Overland flow - Wastewater treatment by grass filtration, flooding or spray-runoff, in which wastewater is applied onto gently sloping, relatively impermeable soil which has been planted to vegetation. Biological oxidation occurs as the wastewater flows over the ground and makes contact with the biota in the vegetative litter.

Raw sewage - Untreated wastewater.

Secondary treatment - Something more than primary treatment, usually treatment by physical, chemical, or biological means such as trickling filters, activated sludge, or chemical precipitation and filtration. Sometimes called mechanical treatment.

CONVERSIONS

1 Acre feet	=	3,060,000 US gallons, or 2,550,000 Imperial gallons
A$	=	Australian dollars
A$1.00	=	US $1.35
US$1.00	=	A$0.74



MELBOURNE AND METROPOLITAN AREA

SUMMARY

This report concerns the Werribee Farm soil treatment area operated by the Melbourne and Metropolitan Board of Works (MMBW). The Board (MMBW) was constituted in 1890 by an Act of the Parliment of Victoria to develop and operate a system of main and general sewerage for the metropolis. James Mansergh, an eminent sanitation engineer from London, submitted eight alternative schemes, five of which involved treatment by land; two, disposal by ocean outfall; and one, by chemical precipitation. Mansergh stated that the Werribee site was situated for land purification of sewage because it was exceptionally dry and had an abnormally low rainfall compared with surrounding districts. His recommendation, based on proven success in England, and on the benefit of irrigation in an area of low rainfall, was for disposal by flood irrigation on prepared land without prior treatment of the sewage. Even today raw sewage is used at the Werribee Farm. Work began in 1892; and in 1897, the sewage from the first property (a hotel) was delivered to the system. Mansergh, of course, could not have foreseen Melbourne's rapid population growth nor the demands that would be placed on the Werribee Farm within 30 years of its establishment. By the late 1930's, the heavy waste loadings had made it necessary to not only enlarge the area of the Farm, but also to complement land filtration (called crop irrigation in the United States) with sedimentation,

grass filtration (overland flow) and lagooning. Despite these additions to the Farm's land treatment operations, the 1897 system remains, to this day, basically as it was originally conceived and build. Even the introduction of the South-Eastern Sewerage System (in 1974) on the opposite side of Port Phillip Bay fulfills Mansergh's original concept of a disposal system serving each side of the Bay. The relationship of the Werribee Farm to the South-Eastern Sewerage System can be seen on the accompanying map of the Melbourne Metropolitan area. In June 1974, there were some 800,000 ratepayers (population 1,880,000) being served by the Board. The Werribee Farm serves about 95 percent of the sewered areas in the metropolis. The balance is served by four other major and two minor systems.

For the fiscal year ending June 1974, the annual per capita cost of the Board's Werribee system was A$1.13 (US$1.53) for 95 percent of the population of 1,880,000. This figure includes all current costs. The capital costs of the land and the original construction were written off years ago. The average daily flow to the Werribee Farm is 125 million British Imperial gallons (150 mgd US).

The principal problem with land treatment at MMBW is caused by the increasing hydraulic load per capita coupled with the increasing population served by the system.

Because the cost of purification at Werribee is substantially less than by mechanical treatment, as well as because the quality of the effluent from Werribee is higher, the MMBW intends to continue to utilize land treatment to the extent possible. However, as the populations of Melbourne and Geelong increase, and the urban areas extend outward toward the Werribee Farm, the acquisition of additional land adjacent to Werribee has not been possible. As a consequence, MMBW is constructing conventional secondary mechanical treatment works and plans to transfer about 45% of the hydrological load from the Werribee Farm to the new South East mechanical system. In spite of this, by 1980/81 the MMBW estimates that the pollutant loading will return to the maximum that the Werribee Farm, as presently operated, can handle.

Currently all sewage to the Werribee Farm is raw sewage. This has been the practice since land treatment was started in 1897. However, in order to provide increased treatment capacity at Werribee, MMBW is giving consideration to using a combination of part primary to full secondary treatment in conjunction with biological processes.

In summary, the MMBW Werribee system is in full operation, is most successful, is substantially lower in annual per capita cost of operations, and MMBW intends to continue to operate its land treatment facilities indefinitely.

LAND TREATMENT IN UNITED STATES

The Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), the legislative history of the Act, and the regulations which have been issued in accordance with the provisions of the Act, provide the statutory basis for consideration and funding of land-application systems in the treatment of municipal wastewater.

The rationale and goals within which land-application systems are to be considered are contained in the following sections of the Act:

Section 208 - Areawide Waste Treatment Management

Section 201 - Facilities Planning

Section 304 - Best Practicable Treatment Technology (BPT)

Section 212 - Cost Effectiveness Analysis

These sections, together with the regulations pertaining to these sections of the Act, and the Program Memoranda to the EPA Regional Administrators, have resulted in a growing interest in the United States in soil treatment systems for municipal wastewater. The EPA Deputy Administrator, on November 1, 1974, wrote to the Regional Administrators urging them to ascertain that the regional review of application for construction of publicly-owned treatment works requires that land application of wastewater be considered as an alternative waste management system. The DA said that the RA's should refuse to fund projects using other systems of waste treatment if it can be demonstrated that land treatment is the most

cost-effective alternative; is consistent with the environmental assessment; and, in other aspects, satisfies applicable tests. This memorandum is attached hereto.

In addition to the potential for being the most cost effective treatment alternative (note the MMBW total annual per capita cost for the fiscal year ending June 1974 is US$1.53 for sewage treatment serving 95 percent of the population of 1.88 million people), another significant reason for the growing interest in land treatment is that PL 92-500 gives authority to the EPA Construction Grants Program to fund publicly-owned soil treatment systems including the acquisition of the land that will be an integral part of the treatment process -- Section 212(2)(A).

The EPA report, entitled, Survey of Facilities Using Land Application of Wastewater by American Public Works Association, identifies certain existing soil treatment systems that were started in the United States as early as 1880. However, these early systems started as disposal projects, and there is a major gap in reliable design data and information. The consequences of this dearth of design information has handicapped the construction grants program, primarily because of the lack of standard criteria. Another deterrent has been the lack of information concerning potential health hazards from soil treatment systems.

Strangely, however, the same dearth of information concerning potential health hazards from secondary treatment and discharge to surface waters has not slowed the demand for the more costly conventional reinforced concrete treatment works. In fact, it seems to me that there could be far greater health hazards from secondary discharge into surface waters because these waters are so often used as sources of potable water by other downstream municipalities.

INTRODUCTION

There are 17 residences located in the midst of the Werribee Farm which are used by farm employees and their families. I visited several of the homes of farm employees, met members of their families including the children, and enjoyed a Sunday picnic on the front lawn of one of these residences. There is no evidence of health hazards caused by sewage irrigation in the adjacent fields, and no concern was expressed by the occupants of these houses about potential health hazards. To the foreign observer that I was, these residences appeared no different than any other farm residences, and their occupants appeared no different than any other farm families, either in Australia or in the United States. Incidentally, on previous trips to Australia I visited many rural communities in every Australian state, except the Northern Territory, and I lived and worked on farms in the United States over a period of several decades.

In my judgment, the farm houses located on the Werribee Farm are better than the majority of farm dwellings in the United States, and the occupants are living under better health conditions than some of their counterparts in both Australia and the U. S.

The Werribee Farm soil treatment system is the outstanding project in Australia from the standpoints of the lowest annual operating costs, success, size and extent of experience with the use of wastewater effluents. The map of Melbourne on page 2 shows the relationship of the Board's Werribee Farm to Port Phillip Bay and the surrounding Melbourne and Metropolitan areas. The South-Eastern Purification Plant (secondary treatment) is also shown on this map.

The Farm has served the residents of Melbourne as a reliable and economical means of wastewater treatment and utilization since 1897. The use of wastewater for irrigation of pasture land. and the subsequent production of cattle and sheep, is an outstanding example of reclamation and conservation. Over the years, however, population and industry have increased greatly. As a result, the Farm is no longer able to cope satisfactorily with the volumetric and organic loadings imposed upon it.

LIVESTOCK AND THE TREATMENT PROCESS

The livestock at the Farm are not only money-earners from the point of view of meat, they are also an essential part of the treatment operations.

Because wastewater treated at the Farm contains a high proportion of natural fertilizers, it promotes a prolific growth of pasture; but since crop irrigation is an efficient method only if the vegetation cover is kept short, cattle and sheep are effectively used to "mow" the grass.

Sheep were introduced to the Farm in 1900 and cattle some 10 years later. In the years since, the Board has sold more than 1.7 million sheep and well over a quarter million head of beef cattle from its Angus and Hereford herds.

Grazing of sheep is on a seasonal basis, and the Board buys the animals in various parts of the southeastern corner of Australia to fatten them for market. The beef cattle, on the other hand, are bred on the Farm and remain there until they are ready for sale. The most suitable animals are retained for breeding and the others are sold as prime meat on the hoof at Newmarket, Melbourne.

Sales of cattle are subject to the condition that they must be immediately slaughtered at an abattoir in the Melbourne metropolitan area, and those killed must undergo rigid inspection. This condition, imposed in the 1920's by the Parliament of Victoria, was a political one obtained by the commercial beef producers and had no health hazard basis.

Diversion to the South Eastern Purification Plant of a portion of the wastewater now reaching the Farm will ease, but not solve, the situation for a number of years, but continued growth in the Western Catchment will produce flows and loadings well in excess of those at present. For example, the loading of biochemical oxygen demand will total about 750,000 pounds per day before completion of the South Eastern Purification Plant; diversion to that plant will remove slightly over 100,000 pounds per day; increased development in the Western Catchment will gain this amount back before 1985; and, less than fifty years hence, the total loading may exceed 1,000,000 pounds per day.

The Farm system serves about 95 percent of the sewered areas in the metropolis. Except for wastes from the greater part of the Municipality of Sunshine, which are discharged directly in the Main Outfall Sewer, and from Williamstown, which enter the main system at Spotswood, all wastes collected by the Farm system flow by gravity through two main sewers - the North Yarra and the Hobsons Bay Main Sewers which unite at Spotswood.

The combined flow then continues for 2 1/4 miles via a 9 ft. 3 in. diameter trunk sewer which terminates at the Brooklyn pumping station. Flows in this sewer enter the pumping station through two penstocks, or control gates, set at the bottom of a well, 144 ft. deep and 22 ft. in diameter. The penstocks control the flow into each of two protective screen wells, 156 ft. deep and 22 ft. in diameter.

From each screen well, the flow continues to its corresponding pump well.

The two pump wells are each 178 ft. deep (internal) and 66 ft. in diameter. Four pumps are installed in each well, and the eight pumps are driven by individual electric motors, the combined rating of which totals 12,800 horsepower. Each pump has a maximum capacity of 42 mgd (50 mgd, US).

When Melbourne's sewerage scheme was originally designed, Port Phillip Bay was selected as the most suitable body of water for the final disposal of the effluents after purification.

The most suitable method of purification known in European countries at the time was land treatment, and the site chosen near Werribee, between the Geelong Road and Port Phillip Bay, possessed all the factors essential for the satisfactory operation of the method--ample area, reasonable isolation, suitable soil and climatic conditions.

An area of 8,847 acres was acquired, and the preparatory work began in 1893. As the city has grown, it has been necessary to expand the Farm area, and today it covers 27,000 acres or nearly 42 square miles.

The Board's Farm at Werribee begain operating in 1897. By 1900, it handled a wastewater flow averaging 12 million gallons per day (14.4 mgd, US). Since that time, the flow has increased as a result of growth of population and industry in the metropolitan area, and at present, averages about 125 mgd (150 mgd, US or 568,650 cubic meters). The mode of operation, originally begun as irrigation of 6,000 acres of

land to produce pasturage for cattle and sheep, has been expanded over the years to include all-year use of anaerobic and aerobic lagoons, sedimentation basins and open sludge digestion lagoons, as well as overland flow (grass filtration) from mid-autumn to mid-spring when irrigation demands are minimal or nil.

Rainfall at the Farm averages 19 in. (48.3 cm.) annually, of which about 12.5 in. (32.2 cm.) of evenly distributed rainfall can be expected during the crop irrigation season; whereas, the evapotranspirational potential during the same period averages about 35.6 in. (90.4 cm.), indicating that a major portion of the annual application of 44 in. (112 cm.) of sewage effluent has evaporated. The daily flows of raw sewage arriving at the Farm vary greatly depending upon rainfall. The current average flow is about 150 mgd (568,650 cubic meters); however, during storm periods peak flows as high as 300 mgd (1,140,000 cubic meters) may occur. Temperature variations are from a low of 40 degrees F (4.4 degrees C) in winter to a high of 112 degrees F (44 degrees C) in summer.

SOIL CHARACTERISTICS

There is no detailed classification of the Farm soils, but the surface of the soil profile consists of a red-brown silt clay loam which is slightly acid. Clay occurs at a depth of about 12 in. (30 cm.). The depth of the clay subsoil is substantial, extending far below any core samples

that have been recorded. The report issued by the U.S. Army Corps of Engineers in January 1974, entitled, "Selected Chemical Characteristics of Soils, Forages, and Drainage Water from the Sewage Farm Serving Melbourne, Australia", contains much detail on soil and forage characteristics.

GENERAL OBSERVATIONS

Many aspects of the Farm operations are praiseworthy. Widespread recognition of the need to conserve or reuse natural resources has evolved only in recent years; however, since 1910 the Farm has reused wastewater from Melbourne for irrigation of pasture land. This process has converted land of little potential for agriculture to prime pasture which now carries over 20,000 cattle and 10,000 sheep. By using the natural resources, water and land, the Farm has marketed more than 270,000 cattle and 1,500,000 sheep since 1910. Taking into account the equipment and manpower costs related to livestock production, the net returns from sales presently average over A$500,000 (US$675,000) per year and significantly reduce the costs directly associated with sewage purification at the Farm. Thus, from conservation and financial standpoints, the Farm represents a valuable resource to the residents of Melbourne.

Initial diversions from the Farm system to the Board's South Eastern Purification Plant are scheduled for 1975. Although this will result in lower loadings at the Farm in the short-term, growth of population and industry tributary to the Farm will generate additional loadings well in excess of those diverted.

FARM OPERATIONS

It is logical to consider operations at the Farm from two standpoints: first, in relation to its primary function for wastewater treatment and second, in terms of its use for livestock production. In addition, approximately three-fourths of the Farm area is a declared Wildlife Sanctuary and provides a habitat for a variety of waterfowl and other birds and animals.

WASTEWATER TREATMENT

In the early years, treatment at the Farm consisted of land filtration by irrigation of pasture land with the underflow collected in drainage channels and discharged to Port Phillip Bay. During winter, wastewater flows in excess of the land's capacity were held in shallow lagoons along the foreshore. Increasing flows during the intervening 70 years have lead to increasing the size of the Farm from about 6,000 acres to nearly 27,000 acres. Of this total, about 17,000 acres are used for some form of treatment, and the balance is devoted to dry grazing, roads, buildings, yards, and other purposes.

The use of grass filtration (overland flow) during winter months began about 1928 and made it possible to phase out the shallow lagoons along the foreshore previously used for winter flows.

Anaerobic and aerobic lagoons were introduced about 1935. Lagoons can handle higher loadings of organic matter than either of the two other methods of treatment, and as a result, their area has been increased greatly in recent years to match increases in loadings. For purposes of comparison, numerical values for the years ending 30 June 1959 and 30 June 1971 are listed in Table A and the monthly variations during each year are shown on Figures 1 and 2.

Table A. Loadings and Treatment Processes, 1959 and 1971

	Year Ending 30 June	
	1959	1971
Total wastewater volume, milllion gallons (US)	35,160	50,900
Average BOD5, milligrams per liter	451	588
Pounds per day	384,000	661,000
Crop irrigation, million gallons (US)	13,320	10,680
Percent of total	38	21
Overland flow, million gallons (US)	13,680	15,360
Percent of total	39	30
Lagoons, million gallons (US)	8,160	24,960
Percent of total	23	49

On arrival at the Farm, the wastewater is distributed to the various treatment areas through a network of channels. Three methods of purification are used. Short explanations of each method along with pertinent comments follow.

Figure 1: Areas used for various treatment methods during 1958/59 at Werribee Farm

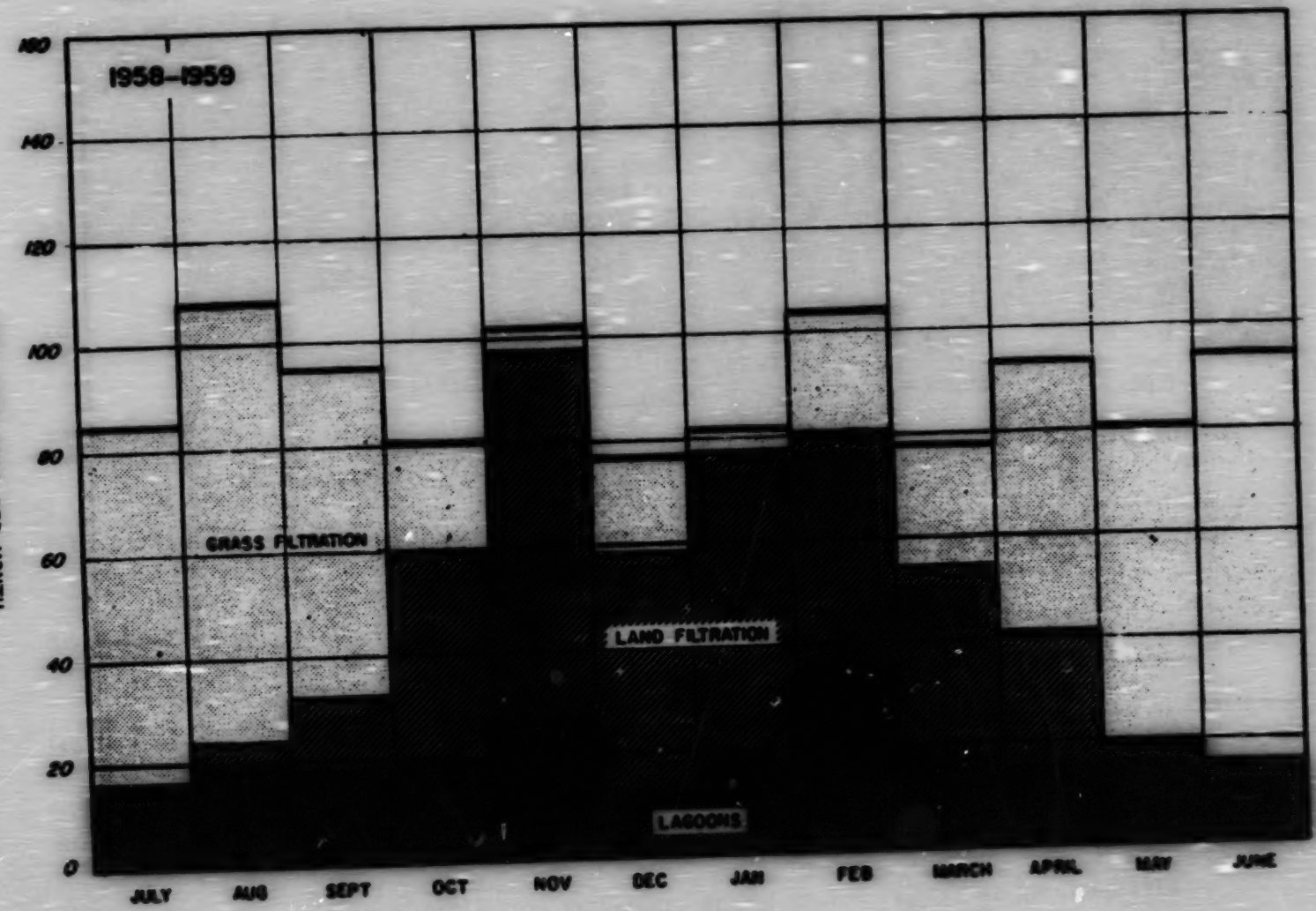
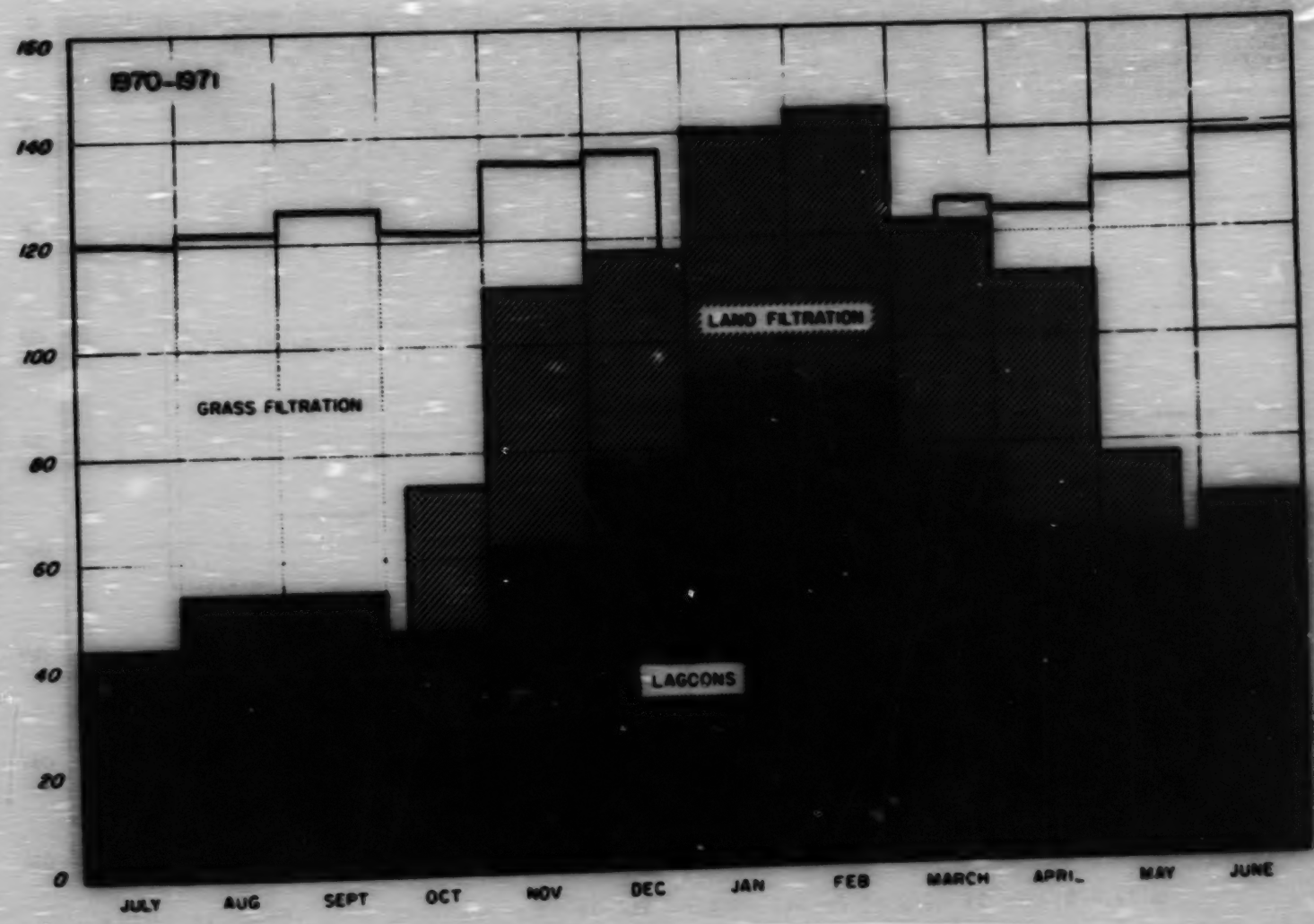


Figure 2: Areas used for various treatment methods during 1970/71 at Werribee Farm



Crop Irrigation (land filtration). This is the primary method which is used throughout the summer. The land filtration areas are carefully prepared pastures, about 20 acres in exent, and divided into 50 bays by low check banks. They are subsoiled, graded evenly and sown with selected pasture grasses.

The wastewater is applied as in normal flood irrigation. Every 18-20 days, each block is covered to a depth of about 4 in. In all, about 600 acres are irrigated each day. The wastewater filters through the soil and when purified seeps into deep earth drains.

The periodic irrigation of pastures with wastes containing a large proportion of fertilizing materials promotes a very vigorous growth of grass. Rotational grazing by sheep, cattle and some horses is essential to maintain these pastures in a condition suitable for continued wastewater purif' :ation.

Application rates for crop irrigation are controlled by the ability of the soil to absorb water, rather than by the strength of the wastewater. Examination of irrigation records from 1935-1971 shows wastewater irrigation depths average about 3.5 feet per year and range between 2.9 and 4.2 feet per year. In a given year, the application rate depends on the rainfall pattern and evaporation. Including annual rainfall, the land receives more than 5 feet of water depth per year. Based on present wastewater strength, the average application rate amounts to 30 lb. of BOD per acre each day.

Crop irrigation is quite effective in reducing the concentrations of many chemical constituents of concern in terms of their effects on the

receiving waters. Compounds of nitrogen, phosphorous, and most of the heavy metals are reduced dramatically. Table B shows results of analyses made on the incoming wastewater and the average for effluent collected from seven different drainage channels which pick up the underflow from the irrigation areas.

Table B. Chemical Characteristics of Untreated Wastewater and Effluent from Crop Irrigation Treatment

Constituent	mg/L Concentrations 1/ Untreated Wastewater	Effluent	Percent Removal
Organic nitrogen	14.3	1.0	93
Ammoniacal nitrogen	35.0	3.2	91
Nitrite	0.75	1.3	-
Nitrate	0	0.4	-
Orthophosphate	26.2	2.6	90
Total Phosphorous	32.1	2.9	91
Sodium	400.0	770.0	-
Potassium	95.0	26.0	73
Calcium	65.0	45.0	30
Magnesium	80.0	107.0	-
Copper	0.45	0.07	84
Nickel	0.20	0.16	20
Chromium	1.0	0.09	90
Cadmium	0.01	0.006	40
Zinc	1.3	0.18	86
Lead	0.55	0.12	78
Mercury	0.0015	0.0003	80

Source: MMBW Analyses on samples collected 17 May 1972.

1/ Concentrations of nitrogen compounds expressed as N; phosphorous compounds as PO_4; all other as the particular element.

Overland Flow (grass filtration). This process is used in purifying the greater part of the normal winter flow when reduced evaporation makes crop irrigation impractical. In this method, the wastewater is first directed into sedimentation tanks, and when the sludge has settled, the water is allowed to flow slowly but continuously over graded areas on which Italian rye grass supplements the natural herbage to make a dense growth. The plants act as a filter in which microorganisms absorb the organic matter in the wastewater so that by the time it reaches the drain, it has the required standard of purity. The overland flow areas are grazed only in the summer when they are not needed for purification purposes.

Detention times are about 2 days. In contrast with crop irrigation, loading rates are governed by wastewater strength rather than by volume. Because of the short detention time, daily loadings rather than long term ones are important. Maximum loadings of about 90 lb. of BOD per acre each day can be handled. In practice, however, it is more convenient to control application by regulating wastewater volume to the overland flow areas. To keep BOD loading rates within the maximum, the volumetric rate of application of sedimented wastewater is held at about 1 mgd per 50 acres. Experience at the Werribee Farm indicates that daily BOD application rates average about 70 lb. per acre.

Oxidation Ponds Treatment. This process operates throughout the year to handle the balance of the normal flows which cannot be treated by the other methods and also copes with the wet weather excess flows. During this treatment, the wastes flow slowly through large areas of shallow ponds where purification is effected by oxygen which is partly absorbed from the atmosphere and partly provided by algae in the presence of sunlight.

Oxidation Ponds. In the lagoon treatment process, wastewater passes through anaerobic lagoons and then through aerobic lagoons. Detention times, relatively short in the former and long in the latter, depend on the rate of wastewater addition, but generally are about one month. BOD loading rates vary with Wastewater strength and the volume added. Experience indicates that average loading rates of about 60 lb. of BOD per acre per day can be handled in winter, while about 100 lb. per day can be handled in summer when photosynthetic activity is greater due to higher temperatures and longer hours of sunlight.

Treatment Efficiency. As shown by the annual averages on Table C, the three treatment processes vary in their ability to remove organic matter and other chemical constituents in raw wastewater. The crop irrigation process is the most effective, but as noted above, area loading rates are low and only about 20 percent of the year's flow at the Farm can be treated by this process. The reductions it achieves in compounds of nitrogen and phosphorous are particularly noteworthy. In raw wastewater given crop irrigation treatment, only 5 pounds pass through the top soil and are found in the effluent. In contrast, the comparable values for overland flow are 40 pounds of nitrogen and 65 pounds of phosphorous, while for lagoons, the values are 65 and 70 pounds respectively. In terms of nitrogen removal, crop irrigation is 8 times more effective than overland flow and 13 times more effective than lagoons. Similarly, for phosphorous removal, it is 13 and 14 times more effective, according to MMBW.

Table C. Estimated Performance by Treatment Processes on Annual Basis

Characteristics	Method of Treatment		
	Crop Irrigation	Overland Flow	Lagoon System
Percent of total flow treated	20	30	50
Percent removal			
BOD	98	96	94
Suspended solids	97	95	87
Total nitrogen	95	60	40
Total phosphorous	95	35	30
Detergent	80	50	30
E. Coli	98	99.5	99.8

Odors. Sources of odors at the Farm have been studied intensively several times, particularly in 1950, 1966, and 1968-1970. The 1966 work disclosed that the "odor potential", based on measured hydrogen sulphide emissions, was four times greater in winter than in summer, and that sedimentation and sludge digestion basins, lagoons, and overland flow areas were the principal sources. Crop irrigation areas and effluent channels were found to be relatively insignificant sources. At each of the major sources, the treatment processes are, or are prone to be, anaerobic. Sedimentation and sludge digestion basins are open, and hydrogen sulphide and other odorous gases are readily released to the atmosphere. The anaerobic lagoons, an inherent part of the lagoon system presently used, are economic on space due to the high BOD loading which they can handle, but are the odorous component. During winter, the area of anaerobic lagoons is greater than in summer, which leads to the release of greater quantities of hydrogen sulphide. In the 1966 tests, this gas was detected over about half of the area used for overland flow.

Livestock Production. Since 1910, the Farm has operated a commercial beef enterprise, producing 20-22 month old steers and fat cull cows for the Melbourne market. During the past 62 years, over 270,000 cattle have been marketed. Since 1946, almost the entire cattle output has been bred and raised on the Farm. In addition, sheep are brought in and fattened on the Farm, and during the same period, more than 1.5 million have been marketed.

Early prohibitions against marketing the cattle for human consumption because of the incidence of beef measles (cysticercosis) were overcome in 1946 by the adoption of the carcass inspection and branding program. In addition, the Farm stock has built up an immunity, and market rejection for this reason is rare -- 29 rejections out of over 116,000 cattle marketed since 1946.

In summary, the principal purposes of operating the Werribee Farm have been to renovate the sewage effluents and to recover resources that could be converted into cash. Research for the sake of research alone has not been a major factor, although some elements of research have been done to seek out solutions to specific problems. The Werribee Farm has 31 test wells for monitoring the influent (daily) and the effluent (twice weekly) to Port Phillip Bay.

The Board has some information on soil analyses at certain locations. In certain small areas affected by salt accumulation caused by groundwater, there is some information. There is limited data on receiving water quality, odors, and potential health hazards, as well as information on BOD, SS, COD, pH, fecal coli, P, total N, nitrate, nitrite and Cl.

CORPS OF ENGINEERS REPORT

In May 1972 a team from the U.S. Army Corp of Engineers made an intensive inspection and study of the Werribee Farm land treatment system. An important aspect, among others, was to learn as much as possible about long term responses of the soil/plant ecosystem to sewage applications. Accordingly, soil and plant samples were collected and analyzed for their nutrient and heavy metal contents.

A report published by the Corps in January 1974, entitled, "Selected Chemical Characteristics of Soils, Forages, and Drainage Water from the Sewage Farm Serving Melbourne, Australia", presents and discusses the findings of this study. Specifically, data resulting from the analyses of soil and plant samples, from sites under irrigation for periods of 48 to 73 years, is discussed in relation to a control sample, length of time under irrigation, resultant water quality produced by the treatment system, and expected ranges of constituent concentrations found in soils and plants from the literature on the subject. A copy of the Corps report is attached hereto.

MOVIE

The MMBW has produced a 16mm film, entitled Werribee - In Harmony with Nature, showing the land treatment operations at the Werribee Farm. This is a nontechnical film, 773 ft. in length. Copies can be purchased from the MMBW. EPA has ordered 10 copies of this film, one for each Regional Office. Persons wishing to buy a copy should address their inquiries to James B. McPherson, Manager, Werribee Farm, Melbourne and Metropolitan Board of Works, 625 Little Collins Street, Melbourne, Victoria 3001, Australia.

REFERENCES

1. Melbourne and Metropolitan Board of Works, Reports, Publicity Brochures, Newsletters, Staff Newspaper, Unpublished Memoranda, Calculations, Lists, Fact Sheets, Charts, Sewerage Committee Notes, Board of Works Notice Papers, and Interviews with Board Officials, Employees and Specialists.

2. Survey of Facilities Using Land Application of Wastewater, Prepared by American Public Works Association, July 1973. No. EPA-430/9-73-006. National Technical Information Service No. PB-227-351-A/S. U.S. Government Printing Office Stock No. 5501-00666; Cat. No. EP2.2:W28/4.

3. Article, Waste into Wealth, Water Spectrum 1972.

4. Report, Program for Development of a Master Plan for Water Quality Management at the Board's Farm, March 1973, by Caldwell Connell Engineers.

5. Data and statistics from certain Principal Persons Interviewed.

6. Data and statistics from Dr. Thomas D. Hinesly, University of Illinois.

7. Notes from personal observations during site visits.

ATTACHMENTS

1. Memorandum from EPA Deputy Administrator to RA's, Nov. 1, 1974.

2. Report, U.S. Army Corps of Engineers, January 1974 "Selected Chemical Characteristics of Soils, Forages, and Drainage Water from the Sewage Farm Serving Melbourne, Australia".

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SUBJECT: Land Treatment

DATE: November 1, 1974

FROM: Deputy Administrator /s/ John Quarles

TO: Regional Administrators

The purpose of this memorandum is to express my concern that EPA must do a better job in assuring that land treatment is given full and adequate consideration as a possible method for municipal sewage treatment in projects funded with Federal grants.

Land application of wastewaters is practiced successfully and extensively in the United States. Many land treatment systems have been in continuous use since 1900. It is apparent from this long-term experience and documented research work that land treatment technology is a viable alternative to be considered as part of waste management systems.

In section 201 of the Federal Water Pollution Control Act Amendments of 1972, it declares that:

> "Waste treatment management plans and practices shall provide for the application of the best practical waste treatment technology before any discharge into receiving waters, including reclaiming and recycling of water, and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution and shall provide for consideration of advance waste treatment techniques".

Pursuant to section 304(d)(2), which directs EPA to publish information on alternative treatment management techniques and systems available to implement section 201, the document "Alternative Waste Management Techniques for Best Practicable Waste Treatment" was published. Therein it considers land application as a viable alternative for best practicable waste treatment.

In addition, the Cost-Effectiveness Analysis Regulations which apply to all projects subject to best practicable treatment state that:

> "All feasible alternative waste management systems shall be initially identified. These alternatives should include systems discharging to receiving waters, systems using land or surface disposal techniques, and systems employing the reuse of wastewater".

EPA Form 1320-6 (Rev. 6-72)

The above requirements shall be met for all projects awarded after June 30, 1974. This means that land treatment must be considered in the basic selection of method for waste treatment.

I urge that you ascertain that your regional review of application for construction of publicly-owned treatment works require that land application be considered as an alternative waste management system. If it can be demonstrated that land treatment is the most cost-effective alternative, is consistent with the environmental assessment, and in other aspects satisfies applicable tests, the Region should insist that land treatment be used and should refuse to fund projects using other systems of waste treatment.

Your director of Water Programs Division has received the draft document "Evaluation of Land Application Systems". This document should be utilized during the review process. Additional assistance can be obtained by contacting the Municipal Construction Division (OWPO), the Municipal Technology Division (ORD), or the Robert S. Kerr Laboratory (ORD).

In order to promulgate proper consideration of land treatment systems by future grant applicants I suggest that the Regional Office provide opportunity for public awareness of land treatment technology. As an example, Region III is planning a two day symposium November 20-21, 1974 at the University of Delaware to highlight land application technology. The idea for the symposium originated in the Regional Office and was planned cooperatively between the regional staff and Office of Water Program Operations headquarters staff. The objective of the symposium is to clarify the technical and policy issues involved and to chart directions for future decisions on land treatment techniques. The symposium will provide useful information to over 300 engineers, scientists, public officials and private citizens. This technique or a similar one could be used by your region to emphasize consideration of land treatment.

Attachment 2 - Werribee

selected chemical characteristics of soils, forages, and drainage water from the sewage farm serving melbourne, australia

JANUARY 1974

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prepared for Department of the Army, Corps of Engineers

SELECTED CHEMICAL CHARACTERISTICS OF SOILS, FORAGES, AND DRAINAGE WATER FROM THE SEWAGE FARM SERVING MELBOURNE, AUSTRALIA

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January 1974

Prepared for

DEPARTMENT OF THE ARMY

Corps of Engineers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

INTRODUCTION

During 1971 the U. S. Army Corps of Engineers embarked upon the new mission of assessing wastewater treatment technology and planning for regional wastewater management systems. The policy was adopted that the Corps would develop several alternative wastewater management plans incorporating advanced-biological, independent physical-chemical, and land treatment technologies. The alternative plans were developed emphasizing the technical goals of producing a high quality of water, i.e., "no discharge of pollutants", and incorporating wastewater reuse, while maintaining an active program of public involvement and education. These plans would then be provided to the public and local decision-makers as viable alternatives to meeting the high water quality goals as required by Amendments to the Federal Water Pollution Control Act, PL 92-500, October 1972.

During the course of the Corps' Wastewater Management Planning Studies many questions and concerns were raised about the state-of-the-art concerning land treatment technology. Specifically, questions were being asked of the Corps such as:

(1) What are the long-term responses of a land treatment system?

(2) Will a land treatment system produce the desired renovated water quality?

(3) What are the effects of excess water, nutrients, and heavy metals on the soil and plant environments?

(4) What are the public health aspects associated with land treatment systems?

(5) Where can one find operating land treatment systems?

Therefore, in an effort to answer some of these questions and better support its planning responsibility, the Corps of Engineers sponsored an inspection trip to the Board of Works Farm, Melbourne, Australia, where raw sewage has been irrigated over a 70-year period. The study team, including agronomists, planners, and engineers under the direction of Major General Willard Roper, Special Assistant to Director of Civil Works for Water Management, Office of Chief of Engineers, U. S. Army, made an intensive inspection and study of the Melbourne system during the week of 15 May 1972.

One important aspect of this inspection trip was to learn as much as possible about long-term responses of the soil/plant ecosystem to sewage applications. Accordingly, soil and plant samples were collected and analyzed for their nutrient and heavy metal contents. The purpose of this report is to present and discuss the findings of this study. Specifically, data resulting from the analyses of soil and plant samples from sites under irrigation for periods of 48 to 73 years will be discussed in relation to a control sample, length of time under irrigation, resultant water quality produced by the treatment system, and expected ranges of constituent concentrations found in soils and plants from the literature.

BACKGROUND

The Board of Works Farm at Werribee was established in 1897, and currently receives raw sewage generated by the 2.5 million people of metropolitan Melbourne, Australia. Contributions to the sewage flow include domestic wastes, industrial wastes, urban storm runoff, and ground water infiltration. The daily amounts of sewage arriving at the Farm vary greatly depending upon rainfall. The current average flow is about 546,000m^3/day (144 MGD), however, peak flows as high as 1,140,000m^3/day (300 MGD) during storm periods occur.

Rainfall at the Farm averages 48.3 cm (19 in.) annually of which about 32.2 cm (12.5 in.) of evenly distributed rainfall can be expected during the irrigation season, whereas, the evapotranspirational potential during the same period averages about 90.4 cm (35.6 in.), suggesting that a major portion of the annual application of 112 cm (44 in.) of sewage water is evaporated.

The Board of Works system utilises three different treatment processes at various times of the year. Land filtration (irrigated permanent pasture), the principal treatment method used throughout the six to seven month summer season, encompasses 4,200 ha (10,376 A) of the total farm and treats about 273,000m^3/day(72 MGD). This process, which is a flood irrigation system using check borders, allows wastewater to percolate through the soil and subsequently

to be collected in deep, open drains or ditches. In 1897 the land filtration area was divided into 8.1 ha (20 A) paddocks consisting of many individual bays which are still being used today. Each bay is 0.16 ha (0.4 A) in extent and surrounded by low check banks to permit a 10 cm (4 in.) application of water without run-off. Initially these bays were deep-plowed to a depth of 76 cm (30 in.) to break up the less permeable subsoil. The irrigation paddocks are sown with a mixture of grasses and legumes to provide balanced pasture production throughout the year. Some of the sewage arriving at the Farm goes through a primary treatment process of sedimentation providing several hours of detention. However, part of the older land-filtration area of the Farm is irrigated with raw sewage without prior sedimentation. Sewage is applied every 18 to 20 days with each block covered to a depth of about 10 cm (4 in.). In all, approximately 243 ha (600 A) are irrigated each day.

The other two treatment methods consist of "grass filtration" (overland flow) which is used in the winter time in lieu of land filtration, and oxidation ponds to handle the balance of the normal flow and wet weather excess. The processes occupy 1405 ha (3472 A) and 1375 ha (3393 A), respectively, while 2,830 ha (7000 A) of the Farm are reserved for dry grazing of livestock. Since these two processes were not specifically the subject of this investigation, they will not be discussed further.

The Farm now includes 109 km^2 (42 mi^2), of which about 70 km^2 (27 mi^2) is devoted primarily to sewage treatment. The 109 km^2 of agricultural land is being used to support a large livestock grazing operation including cattle and sheep.

Soil and Forage Characteristics

Much of the Board of Works Farm is situated on soils derived from either Pleistocene basalt or Pleistocene riverine sediments, which are somewhat variable. The investigations presented in this report are confined to the older part of the Farm which is almost entirely Pleistocene alluvium of the Werribee Series (See Figure 1). These sediments are derived from weathering products of Pleistocene basalt.

Although no detailed classification or mapping has been carried out for the Farm soils, Skene (27) has completed a survey of irrigated soils at the Farm. Typically, the surface of the soil profile consists of a red-brown silty clay loam which is slightly acid. Calcareous silty clay occurs at a depth of about 30 cm where the exchange complex of the clay becomes increasingly dominated by exchangeable Mg and Na with depth. From particle size distribution analyses of six core samples it was found that the soils averaged about 35 percent clay, 45 percent silt, and 20 percent sand. The upper 30.5 to 91.5 cm of the soil showed liquid limits ranging from 32 to 41 (average about 37) and plastic limits ranging from 13 to 22. While the profile is only slowly permeable, the soil can take about 2 cm of water a day. A mixture of grasses includes perennial rye (Lolium pratense), Italian rye (L. multiflorum), white clover (Trifolium repens), strawberry clover (T. fragiferum), alsike clover (T. hybridum), cocksfoot (Dactylis glomerata), timothy

(Phleum pratense), and meadow fescue (Festuca elatior). Perennial rye grass dominates most of the irrigated land, but in successively wetter spots there is marine barley grass (Hordeum marinum) and docks, with water couch (Agropyron repens) in the wettest spots. Under irrigation and with grazing a 2- to 5-cm thick layer of loam rich in organic matter has developed on the surface (20).*

Wastewater Characteristics

Selected chemical and biological characteristics of raw sewage received at the Board of Works Farm in recent time are presented in Table 1. These results represent data extracted from reports of analyses of 24-hour composite samples obtained one day each month over a 13 month period (May 1970 through May 1971). The effluent, as it arrives at the Farm, is approximately twice as strong as we have identified in the United States. The principal reason for this is the relatively low per capita use of water in Melbourne, which is about 0.032 m^3/day (84 gallons per day) at the present time.

*References are at the end of report

Table 1. Composition of raw sewage received at the Board of Works Farm during the period May 1970 through May 1971, in ppm (24 hour composites taken one day each month).

Constituent	Number of samples	Mean	Standard deviation
Total solids	13	1788	515
Volatile solids	13	756	244
Suspended solids	12	473	70
Total nitrogen	13	67.9	13.0
Total phosphorus as PO_4	12	34.5	3.5
Total chloride (as Cl)	9	654	25
BOD (5 days @ 20° C)	12	578	80

Average concentrations of certain heavy metals in raw sewage from analyses of 24-hour composite samples taken during routine sampling one day in each month from June 1968 through November 1969 (composites prepared from grab samples taken at hourly intervals) are presented in Table 2.

Table 2. Heavy metals in raw sewage during the period June 1968 through November 1969, in ppm (24-hour composites taken one day each month).

Heavy Metal	Number of Samples	Mean	Standard Deviation
Ni	13	0.20	0.091
Cu	15	0.64	0.17
Zn	10	1.00	0.58
Cd	3	0.07(1)	--
Cr	15	0.55	0.21
Pb	1	0.55(1)	--

(1) Includes or is sample of 17 May 1972.

Data presented in Tables 1 and 2 provide some information regarding the quality of wastewater that is being applied to the land filtration areas today. The authors have no information on how these data compare with the sewage quality applied over the 70-year history of the site.

PROCEDURE

As previously stated, one of the primary purposes for the Corps of Engineers visiting the Board of Works Farm was to assess the long-term response of soils and plants to nutrients and heavy metals applied as constituents of the sewage used for irrigation. To help identify these responses, T. D. Hinesly and T. W. Whitman as members of the Corps inspection team collected soil, water, and plant samples for laboratory analyses and available historical data. Significant raw sewage quality data have previously been presented. Also use was made of two unpublished reports prepared by V. G. Anderson in 1924 for D. Avery (hereafter referred to as the Avery-Anderson report), who was the advising chemist to the Board. These reports presented results of a chemical examination of raw sewage, soils, and treated effluent for the purposes of determining:

"(1) the nature and amounts of soluble (possible harmful) mineral salts present, and

(2) the fertilizing or manurial values of the samples."

The data contained in these reports for fertilizer or nutrient effects on soils and plants offer a point of historical comparison with existing conditions.

In order to have a basis for comparison, the Corps team took the 1972 soil and plant samples from sites as close as possible to

the 1924 Avery-Anderson localities. The following relationship describes the sample locations relative to each sampling, and is keyed to the sample location map (Figure 1):

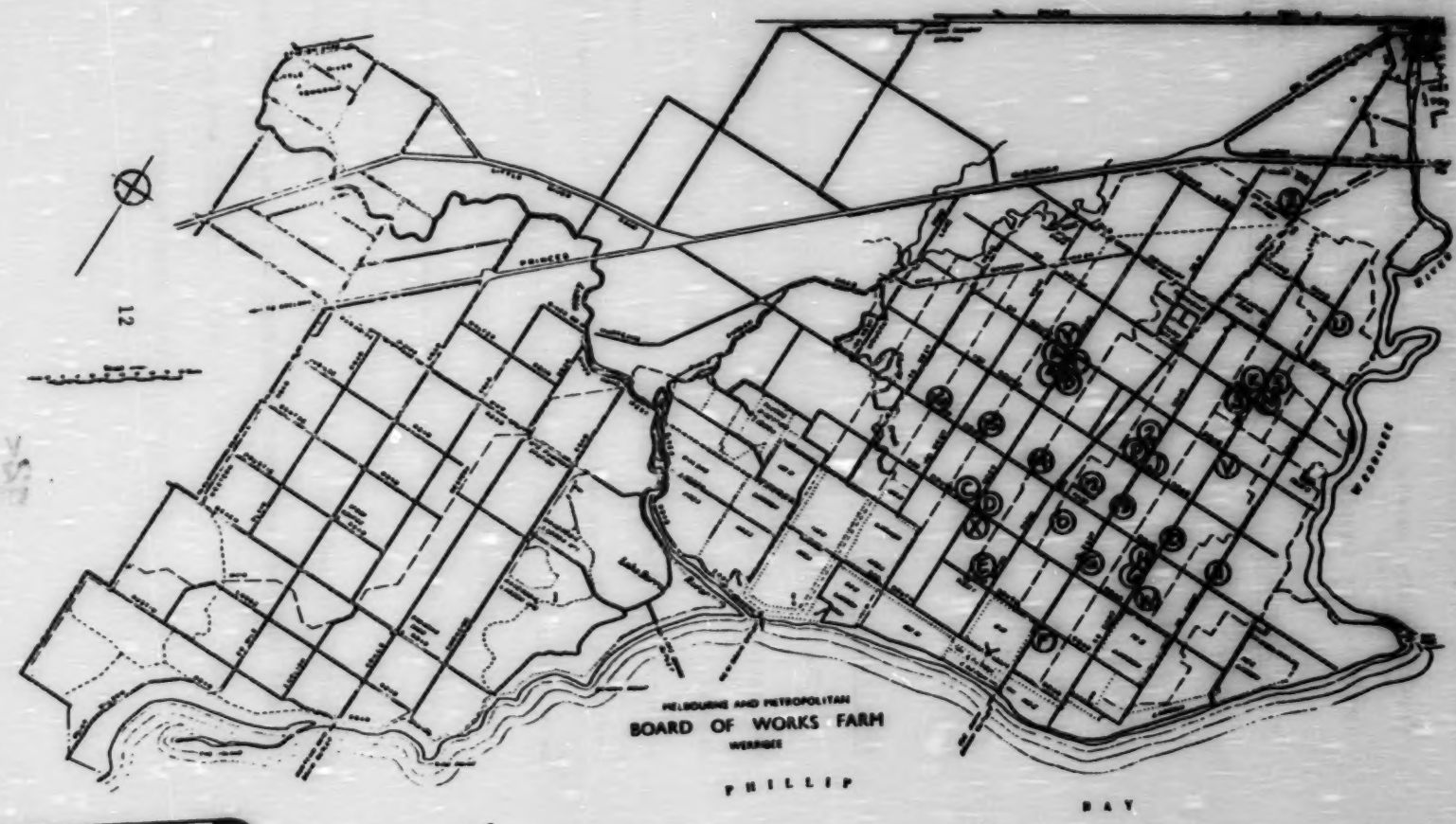
MAP COORDINATE	CORPS OF ENGINEERS SAMPLES (1972)	AVERY-ANDERSON SAMPLES (1924)
65W/90S	1	A
65W/91S	4	B
15E/110S	2	P
50E/39S	3	K
53E/161S	6	H
55E/39S	5	N

Sampling Procedure

The Corps' soil sampling procedure consisted of obtaining a representative sample by augering at each of the six locations to depths of 0-2.5, 2.5-18, and 25-45 cm. Also at sample location 5 a control sample was obtained from an area that had never been irrigated with wastewater. Samples of several thousand grams each were collected, split into duplicates by combining opposite quarters after coning and quartering, and one-half of each was shipped to D. J. David's laboratory in Australia and R. L. Jones' laboratory in Illinois. These sample depths do not necessarily correspond to pedologic horizons of the undisturbed soil profile. Rather they reflect the best estimate of sewage water penetration based on knowledge of the soil's infiltration capacity and water conductivity characteristics. Similarly, plant samples were collected at soil

Figure 1. Site map showing sampling locations

A - P: Sample locations analyzed in Avery-Anderson Report (1924)
1 - 6: Sample locations for U. S. Army Corps of Engineers heavy metal analysis (1972)
10 - 16: Water samples of land filtration effluent (17 May 1972)
U - Z: Sample locations for mechanical analysis (22 May 1972)



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sample locations (except sites 1 and 4) in the form of clippings, bagged, and sent to D. J. David's laboratory where they were prepared for the various analyses by drying and grinding. Samples from sites 1 and 4 are missing because cattle had recently grazed the forage too close to the soil surface to permit collection consistent with that at the other sites.

Laboratory Procedure

The soil samples were air-dried and crushed to pass a 2-mm sieve. For pH determination, soil was mixed with distilled water in a one to one ratio by weight and equilibrated for one hour. For estimation of concentrations of the elements in question that are available to plants, 20 g of each soil sample was extracted with 100 ml of 0.1 N HCl by shaking overnight (18 hours), centrifuged, and filtered through Whatman No. 42 paper. The filtrate was analyzed by atomic absorption spectroscopy. For total analyses of the soils, 0.25 g of soil was digested in a platinum crucible with hydrofluoric acid and eight drops of sulphuric acid, the acid fumed off and the residue taken up in hydrochloric acid and made up to a final volume of 50 ml. Phosphorus was determined by the vanadomolybdate method. An aliquot of this digestion or of one prepared from 5 g of soil and made to a final volume of 25 ml for traces, was used for the determination of total metallic elements by atomic absorption spectroscopy. Carbon was determined by the chromic acid oxidation method, N by the Kjeldahl method (5) and cation exchange capacity by determination of ammonia after saturation at pH 7 and

subsequent displacement from the exchange sites (9). Boron was determined using the methylene blue-fluoroborate complex method '30) in conjunction with HF-acid digestion of the soil minerals. Plant samples were wet digested and made to appropriate final volumes for the determination of major and minor elements.

DISCUSSION

In order to properly assess the information presented it is first necessary to realize what is, and is not, known about the historical operation of Board of Works Farm as it would affect the analyses presented here. Probably the most important and obvious unknown is the quality of wastewater that has been applied over time. This is particularly important in relation to the heavy metal analyses because of the influence of the secular growth of technology and industrialization. For example, we suspect that Pb, Cr, Cd, and Co levels in the sewage have been increasing especially with the war-stimulated industrialization of Melbourne beginning in the 1940's. We have assumed that the quantities of sewage applied to long existing paddocks has not varied substantially from year to year.

Site Selection for Sample Collection

During the sampling phase of the investigation, an attempt was made to collect samples from the center of the irrigation bays. Each bay is approximately 7.6 m (25 ft) wide by 198 m (650 ft) long, so the sampling location would be 92-107 m (300-350 ft) from the outfall structure. Flood-type irrigation introduces water at the head of the field, allowing it to flow over and through the soil, and removes the percolate by seepage into a collection ditch at the down-slope end of the field. Because the wastewater and especially

its solid component is not uniformly spread over the entire field, concentrations of certain constituents will be greatest near the outfall. We do not know the hydraulics of this situation and therefore can not estimate constituent loadings at the various locations. An example of this phenomenon is location Number 3 (Figure 1). The 1924 Avery-Anderson reports (2) referred to this sample as "primarily sewage solids", suggesting that the investigators at the time thought that the sample resembled sewage sludge (indicating a large accumulation of solids and organic matter). In fact, the sampling site was located only 3.66 m (4 yd) from the sewage outfall to the field. This lends some validity to the statement that certain constituents will be greatest near the outfall. In any case, sample locations were ranked according to length of time in service.

Soil Composition

It can generally be stated that if an element is present in greater amounts in the surface horizons than in the subsoil, then this indicates that it is used by vascular plants, transferred to aerial portions of the plant, and held by soil colloids and organic matter against leaching (19). This is certainly true of the macronutrients N, P, Ca and perhaps Mg as shown in Table 3. Soil content of K increases with depth in both the control and treated plots and may be the result of marine water influence on the sediments. This explanation is suggested by the low Ca/Mg ratios and the fairly monotonous distribution of B concentration levels with soil depth.

Table 3. Cation exchange capacity, soil pH, and contents of carbon and total macroelement contents and selected ratios in soils from sewage-amended pastures. Contents in unweathered basalt for comparison.

Site	Depth	Sample Number	C.E.C.	pH	C	N	P	K	Ca	Mg	Ca/Mg	C/N
Years Old(1)	cm		me/100 g		%							
Control Sample	0-2.5	-	22.5	5.2	5.98	0.46	0.053	1.62	0.19	0.10	1.9	13.0
	2.5-18		15.7	5.1	2.59	0.20	0.018	1.76	0.13	0.10	1.3	13.0
	25-45		25.2	5.9	2.03	0.16	0.033	1.94	0.10	0.14	0.71	12.7
48	0-2.5	1	23.0	6.8	6.82	0.65	0.154	1.26	0.39	0.18	2.2	10.5
	2.5-18		15.0	8.4	2.31	0.20	0.092	1.52	0.28	0.12	2.3	11.6
	25-45		14.7	8.6	1.00	0.11	0.065	1.74	0.35	0.14	2.5	9.1
58	0-2.5	4	30.3	6.8	8.84	0.88	0.135	1.19	0.45	0.15	3.0	10.0
	2.5-18		17.3	8.2	2.21	0.22	0.090	1.47	0.25	0.10	2.5	10.0
	25-45		17.3	8.4	0.98	0.12	0.061	1.71	0.19	0.12	1.6	8.2
60	0-2.5	2	28.2	5.7	9.52	0.89	0.157	1.11	0.34	0.099	3.4	10.7
	2.5-18		14.2	6.2	2.23	0.27	0.077	1.34	0.17	0.089	1.9	8.2
	25-45		14.4	6.8	1.02	0.12	0.056	1.36	0.14	0.085	1.6	8.5
60	0-2.5	6	32.2	4.9	16.24	1.57	0.201	1.22	0.50	0.15	3.3	10.3
	2.5-18		25.3	5.4	5.23	0.50	0.161	1.64	0.24	0.11	2.2	10.5
	25-45		23.8	6.2	1.80	0.19	0.076	1.97	0.18	0.19	0.95	9.5
73	0-2.5	5	38.6	5.2	15.94	1.56	0.213	1.10	0.50	0.13	3.8	10.2
	2.5-18		10.7	6.6	1.70	0.19	0.063	1.46	0.13	0.08	1.6	8.9
	25-45		14.2	7.3	0.86	0.15	0.046	1.90	0.14	0.10	1.4	5.7
73 ("Sewage Solids")(2)	0-2.5	5	41.1	5.2	17.80	1.84	0.315	1.40	0.33	0.14	2.4	9.7
	2.5-18		20.3	5.6	3.07	0.34	0.139	1.58	0.17	0.11	1.5	9.0
	25-45		16.5	6.3	0.72	0.12	0.061	1.82	0.16	0.14	1.1	6.0
Basalt (ref. 24) - (Total)		-	--	--	--	--	0.14	0.83	6.72	4.5	1.5	--

(1)Estimated from sample location description in 1924 Avery-Anderson Report with 1972 as reference.

(2)"Sewage Solids" was the description given to the soil sample taken at the Werribee Farm in 1924. The Avery-Anderson Report stated that the sample location was about 3.66 m (4 yd) off the sewage outfall and within 7.6 cm (3 in) of the surface.

Table 4. Comparison of N and P content in soils for the years 1924 and 1972. "Sewage Solids" was the description given to the soil sample taken at the Werribee Farm in 1924. The Avery-Anderson Report (2) stated that the sample location was about 3.66 m (4 yd) off the sewage outfall and within 7.6 cm (3 in) of the surface. Sample number refers to sites located by number in Fig. 1. Data for 1972 come from Table 3 of this paper.

Site	Sample Number	N		P	
		1924	1972	1924	1972
Years old[1]		- - - - - - - - - - - % - - - - - - - - - - -			
Control Sample	-	0.14[a]	0.46	0.013[b]	0.053
48	1	n.d.	0.65	n.d	0.154
58	4	0.13	0.88	0.026	0.135
60	2	n.d.	0.89	n.d.	0.157
60	6	0.24	1.57	0.044	0.201
73	5	0.36	1.56	0.052	0.213
73 ("Sewage Solids")	3	2.16	1.84	0.29	0.315

(a) Range 0.13 - 0.14

(b) Range 0.01 - 0.026

(1) Estimated from sample location description in 1924 Avery-Anderson Report with 1972 as reference.

Comparing the concentration levels of total K, Ca, and Mg presented in Table 3 with the range of levels as given in Table 6 for normal soils, it is noteworthy for future discussion purposes that the Werribee Farm soils have intermediate K and low Ca and Mg contents.

Generally, irrigation with wastewater has increased N and P concentrations of the soil compared to those values reported here for the control plots and those reported in 1924 as shown in Table 4. The concentration of N in the top soil appears to be considerably in excess of the expected normal value found in soils (compare Tables 3 and 6). This suggests that there has been a build-up of organic N in the surface layer over time, while subsoil concentrations have remained rather constant as would be expected.

Phosphorus concentrations in the surface layer fall within the expected normal range for top soil (compare Tables 3 and 6). Khin and Leeper (18) reported that soil total P increased from 513 ppm to 3730 ppm for unirrigated and irrigated samples, respectively. Their work showed that a large percentage of the total P was organic P (35%) with most of the remainder associated with calcium, iron, and aluminum compounds (30, 19, and 10%, respectively). These data indicate a sevenfold increase in total P, whereas, the present study shows four-fold increase in total P of irrigated versus non-irrigated samples (compare control and sample 5). The Avery-Anderson Report (2) indicated values for total P in the range reported by Khin and Leeper and this study for non-irrigated samples. Table 8 shows

approximately a two-fold increase in plant uptake of P for irrigated versus non-irrigated samples.

The C content of the irrigated surface soil has increased markedly over that in the surface horizon of the control sample, with insignificant change in the subsoil. Khin and Leeper (18) reported a similar increase in organic C from 3.7% for unirrigated soils to 10.0% for irrigated soils. Wastewater irrigation and current farming practices have lowered the C/N ratio of the surface soil from about 13/1 to an average of about 10/1. This indicates that there has been a substantial accumulation of nitrogenous organic matter over time.

Cation exchange capacity is closely related to organic C content, increasing by 1.4 me/% C. This relationship is derived from the simple linear correlation of cation exchange capacity with C that yielded the equation

$$Y = 14.67 + 1.40X,$$

where Y is exchange capacity and X is percent C. The correlation coefficient (r) = 0.91. Cation exchange capacity of organic matter in these soils, on the basis of this relationship, is 81.4 me/100 g a value consistent with figures often cited for soils.

Soil pH is an important property in determining heavy metal trace element availability for either plant uptake or leaching. Khin and Leeper (18) reported that soil pH at the Board of Works Farm decreased from 7.5 to 6.2 for unirrigated versus irrigated areas. The pH of the soils sampled in this study are quite variable ranging

Table 5. Contents of microelements and amounts extractable by 0.1 N HCl in soils from sewage-amended pastures. "Sewage Solids" was the description given to the soil sample taken at the Werribee Farm in 1924. The Avery-Anderson Report stated that the sample location was about 3.66 m (4 yd) off the sewage outfall and within 7.6 cm (3 in) of the surface. Average concentrations in unweathered basalt are included for comparison. Sample number refers to sites located by number in Fig. 1.

Site	Depth	Sample Number	Mn		Zn		Cu		Cd		Cr	Co	Pb		Ni		B
			total	ext.	total	ext	total	ext.	total	ext.	ext.	ext.	total	ext.	total	ext.	total
Years old(1)	cm		ppm														
Control Sample	0-2.5	-	244	142	71	16	23	1.1	1.5	0.17	1.1	1.9	44	5.6	30	1.9	4.2
	2.5-18		194	11	60	1.8	21	0.8	1.5	<0.13	1.2	0.93	32	2.2	30	1.0	8.5
	25-45		147	26	84	0.9	47	2.2	2.0	<0.13	1.4	6.5	37	1.1	58	3.0	0.4
48	0-2.5	1	390	200	181	84	69	0.61	<5.0	0.60	1.9	3.5	75	2.2	30	2.5	9.8
	2.5-18		440	212	98	35	65	1.6	<5.0	0.23	3.8	5.1	50	1.1	30	3.0	7.9
	25-45		460	137	79	2.4	69	1.7	<5.0	<0.13	1.6	4.4	50	<1.0	62	6.8	6.5
58	0-2.5	4	400	235	238	127	79	0.61	<5.0	0.77	1.9	4.0	150	2.8	46	2.8	9.0
	2.5-18		490	238	100	36	60	2.1	<5.0	0.17	3.8	4.4	50	3.3	46	3.4	9.5
	25-45		410	160	79	4.8	41	2.1	<5.0	<0.13	2.8	5.6	50	<1.0	30	5.6	11.0
60	0-2.5	2	170	71	177	100	79	2.0	<5.0	0.80	3.1	2.3	50	5.0	46	10	7.8
	2.5-18		200	84	101	32	69	2.9	<5.0	0.33	2.4	5.1	50	3.3	46	4.4	9.3
	25-45		140	39	71	8.6	69	3.0	<5.0	0.23	2.6	5.1	50	<1.0	46	3.0	8.0
60	0-2.5	6	275	187	584	438	129	4.6	5.0	3.94	7.1	2.8	180	11	57	18	5.8
	2.5-18		227	117	296	185	68	7.1	3.0	1.62	6.1	3.0	100	22	46	9.2	9.3
	25-45		225	120	134	43	50	2.9	2.5	0.43	2.5	6.5	44	2.8	76	6.6	9.5
73	0-2.5	5	168	94	244	165	44	1.5	3.0	1.50	2.4	2.1	62	3.9	36	13	7.3
	2.5-18		189	81	77	30	35	3.2	2.5	0.36	2.4	1.9	37	3.9	22	2.5	7.3
	25-45		136	22	70	5.6	48	2.7	2.5	0.20	2.8	1.4	32	<1.0	42	1.8	4.7
73 ("Sewage Solids")	0-2.5	3	297	89	488	340	90	2.6	5.0	3.10	4.7	3.7	243	13	67	32	6.3
	2.5-18		169	70	192	104	61	7.4	2.5	0.73	7.1	3.3	111	33	62	6.4	6.0
	25-45		194	78	134	40	48	4.8	2.0	0.27	2.6	19.6	32	2.8	[illegible]	4.2	3.6
Basalt (ref. 24)-- (Total)		-	1750	--	130	--	100	--	0.19	--	200(2)	45(2)	8	--	160	--	5

(1) Estimated from sample location description in 1924 Avery-Anderson Report with 1972 as reference.

(2) Total contents in basalt.

Table 6. Total and extractable chemical element concentration levels in normal agricultural soils (3, 6, 19, 23).

ELEMENT	TOTAL		EXTRACTABLE (Extracted by 2.5% Acetic Acid)	
	(Range)	(Typical)	(Range)	(Typical)
N %	0.02 - 0.50	--	--	--
P %	0.01 - 0.40	--	--	--
K %	0.17 - 3.30	--	--	--
Ca %	0.07 - 3.60	--	--	--
Mg %	0.12 - 1.50	--	--	--
Mo ppm	0.2 - 5	1.0	0.004 - 0.03	0.005
Cu ppm	2 - 150	20.0	0.05 - 5.0	2.0
Ni ppm	5 - 1000	40.0	0.1 - 5.0	1.0
Zn ppm	10 - 300	70.0	2 - 30	2.0
Cd ppm	0.01 - 10	1.0	--	0.06
Pb ppm	2 - 200	20.0	0.02 - 10.0	0.7
Mn ppm	100 - 10,000	800.0	5 - 100	30
Cr ppm	5 - 1000	30.0	0.01 - 4.0	0.3
Co ppm	1 - 50	8.0	0.05 - 4.0	0.5
B ppm	2 - 150	10.0	0.01 - 10	1.0

from strongly acid (pH 5.1) to moderately alkaline (pH 8.4). In comparison with the acid control site, the irrigated pastures appear to have a higher pH. Heavy metals become more available as pH approaches a value in the lower range of 5 to 6.

From the data presented in Table 5, applications of sewage do not consistantly affect the distribution of total or extractable Mn in the soil profile. Apparently very little of the Mn applied as a constituent of sewage is retained in the soil profile to the depths sampled. Nevertheless, Mn and Fe are relatively unimportant additions in sewage to soils because they are naturally present in soils at relatively high amounts and are already managed or cropped so as not to present a problem to forage production (19). The total soil concentration levels presented for Mn in Table 5 are generally within the range reported in the literature (Table 6) for agricultural soils. All of the total soil concentration levels are at the low end of the range and in fact are several hundred ppm below the "typical" values reported. Whether or not an actual Mn deficiency exists is not discernible from the data or visual observations of the grass plants. Furthermore, a Mn deficiency is not indicated by the extractable soil Mn content which, unlike total soil amounts, far exceeds or is in the upper range of values reported for agricultural soils.

Chromium, like Mn, is added in small amounts compared to native levels and, with the exception of the 60-year treated plot (No. 6), displays only small variation with depth among plots. For the most

part, extractable amounts of Cr are within the concentration levels expected in normal agricultural soils (Table 6).

Except for sample 3, the total concentration levels for Pb presented in Table 5 appear to be within the range of values reported for agricultural soils (Table 6). On the other hand, the total soil concentration levels of Pb are much greater than reported "typical" values for agricultural soils including that from the control site. In all cases upper layers of sewage irrigated pastures contain greater total concentration levels than are found in the surface of the unirrigated area sampled as a control. In the subsoil all Pb concentration levels approach a common, low value which is consistent with the knowledge that very little Pb migrates to lower soil depths with percolating water. However, it was found in only two instances (Numbers 6 and 3) that extractable lead concentration levels in the soil surface had been increased above non-irrigated control levels by sewage irrigation, and in these two instances the extractable lead content exceeds levels reported for normal agricultural soils (Table 6). Because Pb is bound so tightly in surface soil, it is a good index by which to determine how well the analytical results from the soil samples actually reflect the length of time the area has been irrigated with sewage. By using Pb as an index to measure the adequacy of the soil sampling method, the greatest correspondence between total Pb concentration levels in soils and the length of time that the particular area has been irrigated with sewage is found in sample numbers 4, 6, and 3; the order or arrangement in which they are presented in Table 5. The use of Pb values

as an index of the actual amounts of sewage applied seems to be corroborated and warranted by the total C contents and the cation exchange capacity values determined for samples 4, 6, and 3. Thus, in the following discussion concerning the distribution of trace elements as affected by sewage irrigation of pasture lands, a greater emphasis will be placed on comparisons between the analytical results from these three sampling sites in relation to those data from samples representing the non-irrigated pasture.

Under conditions of neutral or alkaline reaction or little soil profile development there is scant change in trace element content with depth (e.g., 14, 28, 31). However, acetic acid extractable trace element contents of soils, especially for well drained podzolic soils where percolation of organic acids is important to development, normally decrease with depth in the soil profile. This phenomenon reflects major shifts in form or in the nature of the compounds in which the trace elements are bound.

Referring to the Zn data in Table 5, it can be seen that in the control sample total concentration levels are fairly uniform with depth, representing a rather "typical" soil content, but extractable Zn concentration levels decrease with soil depth. In view of what has been reported by others with regard to proportions of total and extractable Zn contents, the non-irrigated Werribee Farm soil is typical. Where long-term sewage irrigation has been practiced both total and extractable Zn contents of soils have been substantially increased over those found for non-irrigated plots. Nevertheless, only samples from sites irrigated

for 60 (site 6) and 73 (site 3) years have total Zn contents in the soil surface layer that are much above Zn contents expected in normal soils. It is apparent from these data that much of the Zn applied as a constituent of sewage has migrated to deeper zones in the soil profile and remains in an extractable form. The extractable Zn contents in the surface layer of all the irrigated sites are above the range of concentration levels in normal soils. Even at the deepest soil sampling depth, the portion of the total Zn content that is attributable to sewage irrigations is much more soluble when compared to that in native Zn compounds of the soil.

Recently, Jones, et. al. (16) reported increased uptake of Cd by soybean plants grown on sludge-amended soils. Since increased absorption of Cd by corn plants fertilized with digested sewage sludge had been reported earlier by the same authors (15) many life scientists have become greatly concerned with regard to the potential health hazard of this element to animal and man as municipal wastes are recycled to crop land. Because of the protective action provided by Zn, Fe, Cu, and Se for both plants and animals against the adverse effects of Cd, the toxic hazard is best assessed by considering Cd content in relation to contents of these other trace elements. Therefore, it is important that we consider the relationship between the Zn and Cd content in raw sewage of Melbourne and of these two elements in Werribee Farm soils. First, it should be observed from Table 2 that the Cd content in the raw sewage from Melbourne is higher than expected relative to the Zn content. The Zn to Cd ratio is only a little greater than 14. In sharp contrast with this ratio, it can be

seen in Table 5 that where soils have been irrigated with the sewage for a long period of time the Zn to Cd ratio in the surface layer is in the neighborhood of 100 or somewhat greater than would be expected in normal soils. This relationship is even more important in view of the fact that the unirrigated control sample has a Zn to Cd ratio of about 47. One or a combination of several alternative hypotheses can account for this relationship. The most reasonable explanation is that the sewage samples collected for Cd analyses did not represent average conditions for concentration levels of the element. If the sewage samples taken in 1970 and 1971 are representative for Cd contents, then the concentration levels may have been recently increased by some metal processing waste being discharged into the sewers and this recent change has not yet drastically altered concentration levels of the element in irrigated soils. Alternatively, Cd can be leaching from the soil at a faster rate than Zn, thus widening the ratio. Support is given to this proposition by the decline in ratio size for both total and extractable forms with depth which implies a fast downward movement of Cd relative to Zn.

By comparing the data given for total soil Cu contents in Table 5 with those for normal soils in Table 6, several facts are apparent. For one thing, the non-irrigated soils have total and extractable Cu contents that are within the low end of the ranges as reported for normal soils. Furthermore, the total Cu contents of soils which have been irrigated with sewage for 48 to 73 years are still within the range of values for normal soils, even though concentration levels have been much increased in the soil surfaces and to a lesser extent

in the subsoils. In only two instances (sites 6 and 3) do extractable Cu contents of irrigated soils exceed that expected from normal agricultural soils. In these two instances extractable Cu contents in the 2.5 to 18 cm depth are slightly greater than 7 ppm as compared to a typical value of 2 ppm in agricultural soils.

The total Ni contents for all the soils are within the range of values expected in normal agricultural soils. Unlike several of the other trace elements applied on land as a constituent of sewage, Ni does not appear to accumulate near the surface of the soil. Whatever increases in total Ni contents that have occurred in soils as a result of sewage irrigation reflect that Ni appears mobile and has been fairly uniformly distributed throughout the soil profile. Extractable Ni contents of soils suggest that a substantial amount of that added either remains or becomes extractable by acid. All surface-soil samples from areas irrigated with sewage for 60 or more years have extractable Ni contents that range from 10 to 32 ppm which are higher than the range of values expected for normal soils. These levels are also a substantial proportion of the total. This increase in extractable Ni content of soils irrigated with sewage over that determined for non-irrigated controls appears to be closely associated with the thin soil layer having a relatively high organic matter content.

In the proceedings of a conference held in Champaign, Illinois in 1973 to consider the recycling of municipal sludges and wastewater to land, it was recommended by Chaney (8) that "Toxic metal additions

to agricultural soils should not exceed Zn (equivalent) levels equal to five percent of the C.E.C. of the unamended soil (at pH 6.5 for sensitive crops)". The Zn equivalent referred to is that set forth by Chumbley (10) in which he states that:

> "Advisory experience and the results of pot experiments suggest that copper is twice as toxic as the same amount of zinc and that nickel is 8 times as toxic as the same amount of zinc. Following from this the amount of toxic metal can be expressed as a single figure in parts per million by adding together the zinc content, twice the copper content and 8 times the nickel content and it is reasonable to call this the 'zinc equivalent' of the sewage."

Calculations for "zinc equivalent" relevant to cation exchange capacity are given in Table 7. The "zinc equivalent" has exceeded five percent of the exchange capacity on the pasture represented by sample 6 and sample 3 is very near five percent. These values are conservative because they were calculated on the basis of cation exchange capacity as determined for the respective soil sample. Whereas, according to Chaney's recommendation the cation exchange capacity of the sample collected from the unamended or non-irrigated area should have been used, in which case 8.25 and 8.57 percent of the C.E.C. for the surface-soil samples numbered 6 and 3, respectively, are satisfied by the "zinc equivalent". The reader may recall that the pH values are 4.9 and 5.2 for surface-soil samples numbers 6 and 3 (Table 5) and thus, are considerably below the recommended minimum pH value of 6.5 as suggested for the critical "zinc equivalent". These acid conditions favor absorption of trace elements by plants. However, at the time of soil and forage sampling, no symptoms of

toxicity were apparent. No effort was made to make yield determinations and it is in yield reduction that excesses of toxic elements are first recognized before overt signs of morbidity are apparent.

Plant Composition

In the following discussion of the chemical composition data presented in Table 8, it should be kept in mind that the quantities of trace elements in pasture grasses and legumes vary with species composition, characteristics of the growing season, and stage of growth. Thus, the amount of speculation about the toxicological effects that the concentration levels of the several chemical elements might present to grazing animals is very limited because the data in Table 8 were obtained from only one sampling period.

It was not practical to take plant tissue samples at sites represented by soil sample numbers 1 and 4. The foliage was too short to collect without contaminating the green forage samples with soil. In accordance with the grazing rotation practiced, the cattle had just been removed from the two sites in anticipation of the next irrigation with sewage.

Comparing the chemical composition of the several Werribee Farm samples (Table 8) with the range in chemical composition of common range grasses and legumes as presented in Table 9 provides some insight into the changes in mineral contents of forages growing on soils irrigated with sewage for long periods of time. First, it is evident from the N content of forage samples from irrigated

Table 7. Extractable Zn, Cu and Ni contents of surface-soil horizons expressed as a percentage of the cation exchange capacity. Cu has been adjusted by multiplying that extracted by 0.1 N HCl by two and Ni by multiplying the acid extractable content by eight. These conventions conform to those of Chumbley (10) for the calculation of the "zinc equivalent".

Sample Number	Depth	C.E.C.	Zn	Cu	Ni	Sum
	cm	me/100g	- - - - - - - % - - - - - - -			
Control	0 - 2.5	22.5	0.22	0.03	0.23	0.48
	2.5 - 18	15.7	0.04	0.03	0.17	0.24
4	0 - 2.5	30.3	1.28	0.01	0.25	1.54
	2.5 - 18	17.3	0.64	0.08	0.20	0.92
6	0 - 2.5	32.2	4.16	0.09	1.52	5.77
	2.5 - 18	25.3	2.24	0.18	0.99	3.41
3	0 - 2.5	41.1	2.53	0.04	2.12	4.69
	2.5 - 18	20.3	1.57	0.23	0.86	2.66

Table 8. Chemical composition (as dry weight) of forage samples from paddocks irrigated with sewage for different lengths of time, plus a non-irrigated control site.

Site	Sample Number	N	P	K	Ca	Mg	Na	Mn	Zn	Cu	Cd	Cr	Co	Pb	Ni	Fe
		%						ppm								
Years old(1)																
Control Sample	-	1.80	0.29	1.90	0.33	0.23	0.29	149	50	6.5	0.77	6.9	<0.64	<2.5	2.7	970
60	2	4.01	0.60	2.93	0.29	0.20	0.83	49	63	12	0.89	9.8	0.64	<2.5	4.9	361
60	6	3.44	0.56	3.01	0.36	0.20	0.88	54	150	19	1.28	28	<0.64	<2.5	9.1	987
73	5	3.85	0.60	3.11	0.22	0.19	0.62	44	58	11	0.64	6.9	1.28	<2.5	2.7	602
73 ("Sewage Solids")(2)	3	3.73	0.52	2.74	0.34	0.25	1.03	58	144	13	0.90	13	1.28	<2.5	6.6	499

(1) Estimated from sample location description in 1924 Avery-Anderson Report with 1972 as reference.

(2) "Sewage Solids" was the description given to the soil sample taken at the Werribee Farm in 1924. The Avery-Anderson Report (2) stated that the sample location was about 3.66 m (4 yd) off the sewage outfall and within 7.6 cm (3 in) of the surface.

Table 9. Range of chemical composition of common range grasses and legumes (15,19,21), dry weight basis of green roughages. No implication is intended that the mean is equal to the median value within each range.

ELEMENT	RANGE
N %	2.55 - 4.06
P %	0.19 - 0.45
K %	1.16 - 2.76
Ca %	0.62 - 0.90
Mg %	0.15 - 0.35
Na %	0.30 - 0.45
Mo ppm	0.1 - 4.0
Cu ppm	2.0 - 15.0
Ni ppm	0.1 - 3.5
Zn ppm	8.0 - 60.0
Cd ppm	0.2 - 0.8
Pb ppm	0.1 - 10.0
Mn ppm	15.0 - 200.0
Cr ppm	0.1 - 0.5
Co ppm	0.05 - 0.5
B ppm	1.0 - 80.0
Fe ppm	250.0 - 600.0

and non-irrigated plots 'hat long-term application of sewage has resulted in significant increases of this element. Nitrogen concentration levels in the plant tissues from the control site are below, whereas those from irrigated pastures are within, the range of values expected in a mixture of grasses and legumes. Also, the plant tissues collected from the non-irrigated site have P contents within the expected range of values, but those from irrigated sites have concentration levels much above the normal range of values. Relatively speaking, the K contents of irrigated plants have not been increased over those from the control site to the same extent as the increases in N and P. In comparison to typical contents, the K concentration level in the foliage from the control site is about what would be expected. Sewage irrigations have caused K concentration levels to be increased in plant tissues but the percent increase is less than for N and P. In spite of the relatively high uptake by plants growing on the control plots, K concentration levels were increased in every instance by sewage irrigation and, except for grass samples collected at site number 3, all have K contents above the range of values for common pasture grasses. In sharp contrast to N, P, and K, the contents of Ca and Mg in plant tissues have not been increased by sewage irrigation. In fact, there appears to have been little if any change in Ca and Mg content as a result of sewage irrigations. At the same time, Ca contents appear to be lower than that of common range grasses, whereas Mg contents are within the expected range of

values. Considering all of the elements absorbed in large quantities by plants, the Na content of plants appear to have been increased to the greatest extent by sewage irrigation. In all the areas irrigated with sewage the plants growing there contain 2 to 3 times more Na than those growing on the non-irrigated area. It is significant that the Na content was increased from a value just below that expected in common range grasses and legumes to contents much above the expected range of values with sewage irrigation. Although we don't know how to assess the increased Na contents resulting from sewage irrigation as it affects the health of cattle and sheep consuming the forage, it seems appropriate to discuss the increased contents of K in forages with irrigation and the lack of change in Ca and Mg contents in regards to animal health.

A morbid condition often called grass tetany or staggers, and more appropriately known as hypomagnesia by animal scientists and veterinarians has been observed in cattle and sheep at various locations throughout the world. It is characterized by convulsions and paralysis in animals having low Mg concentration levels in blood serum. The disease was recognized in beef cattle many years ago by the veterinarian serving the Werribee Farm and is now avoided by adding MgO to the dry hay fed to the animals. This disease is not only endemic to Werribee Farm, but rather is also widespread in Australia and especially on areas with similar deltaic soil types.

Grass tetany occurs when Mg is available in amounts which are inadequate to meet metabolic demands. It is not a true deficiency

of Mg in that it is conditioned by a number of factors such as the K, crude protein, and organic acid contents of forages. In turn the forage contents of these three substances are influenced to a large degree by N and K fertilization, environmental temperatures, and the availability of soil moisture. All of these factors have been discussed in some detail by Cline (11). In 1957, Kemp and 't Hart (17) reported that a significant correlation existed between the number of grass tetany cases in cattle and the ratio of K/Ca + Mg, calculated as the milliequivalents per kilogram of each element in forage samples. When the value of the K/Ca + Mg ratio was less than 2.2 they found very few grass tetany cases but when the ratio was above this critical value they found 6.66 percent of 1908 head of cattle in their study suffered the disease. They also present evidence that as the K/Ca + Mg ratio increases in the pasture forages above the critical 2.2 value, incidence of the disease increases. When the ratio lies between 3.01 to 3.40, 15 to 20 percent of the animals may contract the disease.

Because large quantities of K are supplied to the Werribee Farm soils by sewage irrigation and under a grazing system very little K is removed, it is of some importance to know how the K/Ca + Mg ratio have been affected. Not more than 10 to 20 percent of the three elements involved in the ratio would be removed from the irrigated areas as body constituents of the beef cattle and sheep taken for slaughter. Therefore, the major portion of these three elements, supplied in the sewage, remains on or in the soil unless removed in the drainage water.

In Table 10 it can be seen that the K/Ca + Mg ratio values as determined for the Werribee Farm forage plants are below the critical value of 2.2 only in the samples from the non-irrigated area and in sample 3 collected from an area which has been irrigated with sewage for 73 years. Forage samples from all the other irrigated sites have K/Ca + Mg ratio values that exceed the critical value and thus indicate a potential grass tetany problem when sewage is used to irrigate pastures on soils having low Mg contents. A strong inverse relationship exists between the K/Ca + Mg values in forages and similar ratio values calculated from the total contents of the three elements in soils. The simple linear correlation of plant ratio (Y) with that in soil (X) gives $Y = 3.24 - 0.834X$ with $r = -0.865$ ($r \geq 0.878$ at $P = 0.05$). In view of the data presented in Table 3, it appears that small decreases of K and increases of Ca and Mg contents in soils have occurred as a result of sewage irrigation. These results are indeed surprising and are all the more impressive because they have been observed from the collection of such a few samples. It is regretable that K was not included in the analyses of water in the drains.

In view of the decreased soil contents it appears inconsistent for the K content of the forage samples to have been increased by sewage irrigations. Furthermore, N is reported by Schütte (25) and Emmert (13) to be antagonistic to the absorption of K by plants while at the same time stimulating uptake of Mg. However, the correlations between K/Ca + Mg ratio values and N contents in forage samples from Werribee Farm do not reflect these kinds of interactions. A positive correlation

Table 10. Ratios of K/Ca + Mg (calculated as me/kg) in forages and soils and N contents in forages. Content of N is included from Table 8 for comparison.

Site Years Old	Sample Number	$\frac{K}{Ca + Mg}$		% N in Forage
		Plant	Soil	
Control	-	1.37	2.34	1.80
60	2	2.42	1.13	4.01
60	6	2.24	0.84	3.44
73	5	2.99	0.79	3.85
73	3	1.87	1.28	3.73

between the K/CA + Mg ratio values and N content, yielding $Y = 0.53 + 0.40X$ with $r = 0.782$ ($r \geq 0.805$ at $P = 0.10$) is almost significant. Therefore, the interaction effects between N, K, and Mg appear contrary to what is generally reported for plants. More thorough study of pastures on the Farm may establish this relationship more firmly. On the other hand, Zn, Cu, Mn, and B stimulate the uptake of K and their influence apparently is the dominant or controlling factor in the sewage irrigated vegetation.

Among the results of analyses of forage samples for 15 chemical elements (Table 8), Mn concentration levels are the only ones which appear with any degree of certainty to have been decreased by sewage irrigation. But even though Mn contents have been decreased they are still within the range of values expected in common range grasses and legumes. In general, Mn absorption by plants is enhanced by K and depressed by Ca and Cu. Thus, it appears that even though Mn absorption has been decreased by sewage irrigation the overall effect is one of stabilizing the uptake at an adequate level in plant tissues.

Zinc contents of forage samples reflect the sewage irrigations to the greatest extent in only those samples from the two sites numbered 6 and 3. It may be recalled that by the use of Pb as an index, it is these two sites which we estimate have received the greatest loading rates of sewage during the history of the Farm. At these sites Zn contents of the vegetation are more than twice the highest values expected in common range grasses and legumes. The fact that Ca and P are antagonistic to Zn uptake by plants may account for the high but

reasonable levels of Zn in foliage tissues. Since the Ca content is low, P is probably the element which exerts the major control over Zn absorption and translocation to aerial tissues.

From the comparison of Cu contents of the green forage samples from the non-irrigated control site to that contained in all of the samples from irrigated areas, it is obvious that this metal has been much increased in the vegetation (Table 8). Nevertheless, only in the sample from irrigated site 6 does the vegetation contain Cu contents in excess of that which has been reported as normal values (Table 9). Like Zn, the Cu content of the vegetation is probably maintained at a tolerable level by the plant available P supplied as a constituent of the sewage and accumulated in the soils. Unusually high levels of available soil P are known to be antagonistic in the uptake of Cu by plants.

All of the forage samples collected from sewage-irrigated sites, except sample 5, have Cd contents that barely exceed levels expected in common range grasses and legumes. It may be recalled that the increasing Zn to Cd ratios of extractable contents in soils with increasing loading rates of sewage were discussed above and it is of some interest to note a similar trend for the ratio values in the vegetation. In every case the Zn to Cd ratio values are greater in forage samples representative of irrigated sites than the ratio value of 65 determined for the sample from the non-irrigated control plot. It is especially noteworthy that for samples numbered 6 and 3, (sites that have had the greatest amount of sewage applied according to the

use of the soil contents of Pb as an index) the Zn to Cd ratio values are 117 and 160, respectively.

In view of the reasonable extractable concentration levels in the soils, the exceedingly high Cr contents in forage samples from both irrigated and non-irrigated sites on the Werribee Farm can not be explained. From a review of the literature for reported Cr contents found in a number of plant tissues, including pasture grasses, Underwood (29) found 0.1 to 0.5 ppm to be the expected range of concentration levels and these are the values included here in Table 9. The Cr concentration levels reported here for forage samples are presented with reservations until additional samples can be collected and analyzed. Because Cr is so poorly absorbed by animals and has such a low order of toxicity, even if concentration levels in Table 8 are correct values they would not be considered to be a health hazard to sheep and cattle.

Even though it can not be said with any degree of certainty from the data in Table 8 that sewage irrigations have increased the extractable Co content of soils, it appears that concentration levels are enhanced in the forage. Although three of the forage samples from sewage irrigated pastures contain Co contents that exceed values reported for common range grasses and legumes, the concentration levels do not seem excessive from the standpoint of animal health. Like Cr, Co has a fairly low order of toxicity in animals (29).

As discussed above, irrigation of pastures has substantially increased total and extractable Pb contents of some of the soils and

thus it is somewhat surprising that the Pb content of the forage grown on the pastures is not considerably higher than that found in the forage sample from the non-irrigated control site. None of the forage samples contained Pb in concentration levels equal to the higher values expected in common range grasses and legumes.

Although three of the forage samples from sewage-irrigated sites have Ni contents that exceed the highest values expected in normal pasture vegetation, no adverse symptoms of high Ni levels were apparent. With regard to untoward effects in animals, Ni is like Cr in that it is poorly absorbed from ordinary diets and is relatively nontoxic (29). It appears rather unlikely that the Ni contents of any of the forages grown on the Werribee Farm pastures represent a Ni-related health problem to animals.

As can be seen in Table 8, the Fe contents of forage samples are highly variable. The Fe content of the forage sample from the control or non-irrigated site is much higher than that expected for normal pasture vegetation. Except in the forage sample from site 6, sewage irrigation appears to have decreased the uptake of Fe by plants. But all of the forage samples have Fe concentration levels equal to or greater than would be expected as an average value. The fact that the greatest Fe content occurs in the sample from irrigated site 6 is of special interest, because this sample also contains the highest concentration levels of Ca, Zn, Cu, Cd, Cr, and Ni. Except for Cr, all of these chemical elements and Mn are known to be antagonistic to the absorption and/or translocation of Fe into plant foliage. On the other

hand, K stimulates the uptake of Fe by plants and therefore may be the off-setting or protective factor against an Fe deficiency (25).

Water Composition

For a description of the surface drainage system, the reader is referred to the article entitled "Waste into Wealth" which appeared in the 1972 Fall issue of Water Spectrum (26). In the following brief discussion of the chemical content of the drainage water from the Werribee Farm, it should be kept in mind that the objectives of the Melbourne Board of Works staff at the time the farm was established in 1893 was to use this system to reduce the suspended solids to less than 30 ppm and the biochemical oxygen demand to less than 20 ppm prior to discharging the wastewater to Port Phillip Bay. To this end, the Farm has been successful, even though the raw sewage waste loads soon exceeded the designed capacity of the Farm after its establishment. Thus, this farm was never selected nor was the system designed to treat raw sewage to the level of "no discharge of critical pollutants" which will be the United States' goal in designing future land treatment systems to achieve tertiary treatment of and nutrient removal from wastewaters.

If we assume a hydrologic equilibrium, that one volume of water added to the paddocks is represented by one volume in the drains, then it can be inferred from the data in Table 11 that 88 percent of the N and 91 percent of the P is being removed from the raw sewage. If evapotranspiration losses (90.4 cm) are considered for this area

where annual precipitation is about 50 cm, than N and P removals on a mass basis are even higher. The averages of 5.9 ppm of total N and and 2.9 ppm of total P in drainage waters are considerably lower values than the 20 ppm and 10 ppm reported as typical values for N and P, respectively, in secondary treated effluents (22). Although the N and P concentration levels in the farm drainage water are several times greater than the levels expected in Port Phillip Bay (assuming average composition of seawater as shown in Table 11), it is nevertheless of higher quality with respect to these two elements than could have been achieved by a secondary wastewater treatment plant. It was mentioned before that it is regretable that K concentration levels in sewage and drainage waters were not determined for use in estimating the K mass balance, but from the standpoint of the quality of water discharging to Port Phillip Bay it is not an important parameter. Seawater normally contains about 380 ppm of K and it seems highly improbable that the farm drainage waters would contain higher concentration levels. And even if they did the values would have little relevance to the pollution of Port Phillip Bay.

Of the six heavy metals whose concentration levels were determined in drainage waters, Ni is removed to the least extent by the soil-plant system (Table 11). In spite of the fact that the soil-plant complex removes only about 20 percent of the total Ni contained in raw sewage, it does not appear likely that secondary treatment would reduce the Ni content to lower levels. An average value for Ni concentration levels in secondary effluents has been reported to be about 0.2 ppm (23). By

Table 11. Comparison of concentration levels of selected chemical elements occurring in water draining from irrigated paddocks with those present in the raw sewage, secondary effluent, and seawater (22, 24).

Effluent Sample Location[1] (See Figure 1)	Total N	Total P	Ni	Cu	Zn	Cd	Cr	Pb
	ppm							
55E/160S	5.5	1.8	0.15	0.10	0.13	0.01	0.05	0.13
95E/160S	10.8	8.4	0.20	0.01	0.20	0.008	0.15	0.13
5W/160S	6.0	2.0	0.13	0.08	0.08	0.005	0.05	0.10
15E/160S	5.5	1.6	0.18	0.08	0.08	0.008	0.05	0.14
45W/160S	4.7	0.9	0.20	0.15	0.65	0.008	0.10	0.15
85W/160S	5.0	4.9	0.10	0.05	0.10	0.005	0.05	0.08
125W/160S	3.9	0.9	0.15	0.05	0.04	trace	0.03	0.11
Average for 7 samples	5.9	2.9	0.16	0.074	0.183	0.0063	0.07	0.12
Raw Sewage Channels[2]	50.1	32.1	0.20	0.64	1.0	0.07	0.55	0.55
% Removal	88	91	20	89	82	91	87	78
Secondary Effluent	20	10	0.2	.04-0.1	.06-0.2	0.1	.01-0.2	.01-0.1
Composition of Seawater	0.03 - 1.0	0.001 - 0.10	0.0001 - 0.0005	0.001 - 0.09	0.005 - 0.014	.00011	0.00005	0.004 - 0.005

(1) Analyses of samples of drainage effluent from sewage irrigated pastures collected from separate drains at the 160S road on 17 May 1972.

(2) Total N and P values for raw sewage are single samples of 17 May 1972; data for heavy metals are from Table 2, this report.

either treatment method the Ni content in waters discharged to Port Phillip Bay would continue to be greater than is normally found in seawater.

Again, with respect to the contents of the six heavy metal species determined in the drainage waters, only Cu is within the range of concentration levels expected in seawater. Furthermore, Cu concentration levels in the Farm drainage water are about the same as levels expected in municipal effluents having secondary treatment.

A comparison between the raw sewage contents of Zn, Cd, Cr, and Pb with their concentration levels as determined in drainage water (Table 11), indicates that the irrigated-pasture system is removing 78 to 91 percent of these chemical elements. These removal rates are as great if not greater than can be achieved with a well managed secondary treatment plant. However, the concentration levels of all of these four metals are higher in drainage water than would be expected in seawater. On the other hand, we do not have concentration levels of the several chemical element species in drainage water from similar basalt derived deltaic soils irrigated with waters other than that of raw sewage. Thus, we don't know the contribution of native mineral weathering to concentration levels in drainage water.

Because of odor problems if for no other reason, it does not seem likely that sanitary district staffs in more densely populated areas of the United States will consider the use of untreated sewage to irrigate pastures and crop lands. On the other hand, a rapid increase in the use of secondary treated effluents for irrigation can be

expected as laws and regulations are enforced requiring tertiary treatment of municipal effluents before discharge to streams. Already treated effluents from many municipalities in arid and semiarid regions are used to irrigate golf courses, parks and crops of various kinds. Many of these operations provide the opportunity to determine the efficiency with which soil-plant systems remove nutrients and trace elements from the applied effluent. Such information would be more relevant to future land treatment systems than that reported here. The results reported here are from a system that has been stressed with considerably higher concentration levels of macronutrients and trace elements than would be applied where only secondary effluents are used for irrigation over an equivalent period of time. But the Werribee Farm analyses are valuable from the standpoint of illustrating the tremendous capacity of the soil-plant complex to attenuate water pollutants by precipitation, adsorption, absorption, and assimilation. Furthermore, the results demonstrate the capacity of growing plants to buffer the effects of abnormally high soil contents of essential and non-essential chemical elements on animal health.

SUMMARY

From the results of this cursory investigation of the chemical characteristics of sewage, soils, forage, and drainage waters from the Werribee Farm, some of the more important observations are as follows:

1. The irrigation of pastures with raw sewage at an annual rate of about 111.8 cm (44 in) per year for a period of 48 to 73 years has resulted in increased soil contents of N, organic C, and P. As C increases, cation exchange capacity increases 1.4 me per percent C. Soil C/N ratios decrease with sewage irrigation while Ca/Mg ratios increase indicating greater accumulations of N and Ca relative to C and Mg, respectively. Contrary to what was anticipated, soil K contents remain unchanged or declined with sewage irrigation.
2. With some exceptions total soil contents of all trace elements included in the soil analyses were increased by sewage irrigation. However, increases for total contents of both Ni and B were consistently less than anticipated in view of amounts contained in sewage. In spite of small increases in total Ni, extractable soil contents of Ni were increased to levels considerably higher than in normal soils. In general trace element contents extractable with 0.1N HCl increased with sewage irrigation, most notable of which was Zn. Contrary to expectation, Zn to Cd ratios of both total and extractable contents in soils were increased with sewage irrigation. From

the calculation of the "Zn equivalent," as proposed by others as a means for limiting municipal waste application on land, it is evident that at two sites, loading rates have already exceeded recommended amounts.

3. Sewage irrigation of pasture land has resulted in increased or unchanged forage contents of all the chemical elements determined, except Mn. This one element was decreased, but not to the extent that it would be considered to be at a deficiency level in grasses and legumes. Large increases in forage contents of N, P, K, and Na have occurred as a result of sewage irrigations. Calcium and Mg contents of forage have not been changed by irrigation. Because of the increased uptake of K by plants in the presence of little change in Ca and Mg contents of forage, irrigation has increased the probability of grass tetany in cattle and sheep. In at least two of the forage samples from irrigated pastures, Zn, Cr, and Ni contents were considerably greater than would be expected in normal grasses and legumes. But the concentration level of Cr was also higher in the forage sample from non-irrigated control sites than expected. These three essential elements for animals have a low degree of toxicity and thus their concentration levels do not indicate harmful effects to animal health. In terms of animal health there are no indications that forage from irrigated sites contain trace elements in either excessive or deficient amounts.

4. Results of this investigation suggest that drainage effluents from the Farm contain considerably less N and P than is generally found in secondary effluents from biological wastewater treatment plants. Therefore it is concluded that the Melbourne Board of Works sewage irrigation operation has provided a greater degree of protection against the pollution of Port Phillip Bay than could have been obtained by biological secondary treatment. Concentration levels of several heavy metals in the Farm drainage water are about the same as expected in secondary-treated municipal waste waters. Except for Cu, all of the elements included in the analyses of farm drainage water occur in higher concentration levels than would be expected in seawater.

5. Hopefully this cursory examination of a sewage farm has contributed information toward answering some of the more salient questions about land disposal of raw sewage and will stimulate a more comprehensive study of the Melbourne operation, the objectives of which should be the establishment of the mass balances of the macro- and microelements in this system and the accurate description of the chemical and physical mechanisms operating in the system. Data from sewage farms that have been in operation for long periods of time are useful for predicting the fate of many water pollutants, particularly where their contents in untreated sewage results in application rates on soils which are considerably greater than would occur on a land treatment system utilizing secondary effluents.

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